

# IoT Product Design and Rapid Prototyping

Brian Rashap

January 2023

# Class Logistics



# Brian Rashap, Ph.D.

- Proud husband of Krista and father of Shelby (24) and Ethan (21)
- Electrical Engineer with 25 years industrial experience
- Hobbies: running, cycling, reading, spending time with family





# Edward (EJ) Ishman

- Loving father of two exceptional children Ziona (7) and Iree (5)
- 4 years as an Aerospace Maintenance Journeyman (Crew Chief) in the United States Air Force
- CNM Ingenuity IoT Bootcamp graduate (Cohort 6)
- Hobbies: Photography, Live entertainment, exploring the outdoors, thrifting.





# Introductions

## INTRODUCTIONS



# Class Rules

- Respect each other. Help each other.
- Ask questions.
- Be on time (let us know via Slack if you won't be here)
- Keep your workspace and the classroom neat and tidy.
- If you are struggling, let me, Susan, or Esteban know. We are here to HELP!
- Class hours
  - Mon-Th: 8am to 5pm <sup>1</sup>
  - Friday: 8am to 3pm <sup>2</sup>
  - Lunch Break: 1 hour near noon. Maybe combined with work time.
  - Please respect Brian and Christian's lunch break as well.

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<sup>1</sup>Doors open at 7:50, please be in your seats ready to learn by 8:00

<sup>2</sup>Occasionally on Friday there will be optional activities from 3 to 5



# Grading

Assignments total 1000 points. To graduate, you need to earn at least:

- 750 total points
- 200 points (80%) on the Capstone.
- 65 points (65%) on Quizzes, the two Midterms, and Solidworks.

## Point distribution

- ① IoT assignments + Lab Notebooks: 300 points <sup>3</sup>
- ② 3D modeling (Solidworks) assignments: 100 points
- ③ Weekly quizzes: 100 points
- ④ Midterm Projects: Smart Room Controller/Plant Watering System: 100 points each (200 total)
- ⑤ Team Capstone Project: 250 points
- ⑥ Professional Development: 50 points

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<sup>3</sup>All coding assignments must follow style-guide



# Credit for Prior Learning (CPL)

| Approved for CPL   |  |
|--|--|
| CIS 1605   | Internet of Things                               |
| CIS 1275   | Introduction to C++                              |
| BCIS 1110  | Fundamentals of Information Literacy and Systems |
| BUSA 1130  | Business Professionalism                         |
| BUSA 1198  | Project Management Fundamentals                  |
| CSIS 1151  | Intro to Programming for Non-Majors of CS*       |
|  |  |
| * CSIS 1151 credit requires appropriate math prerequisites |  |

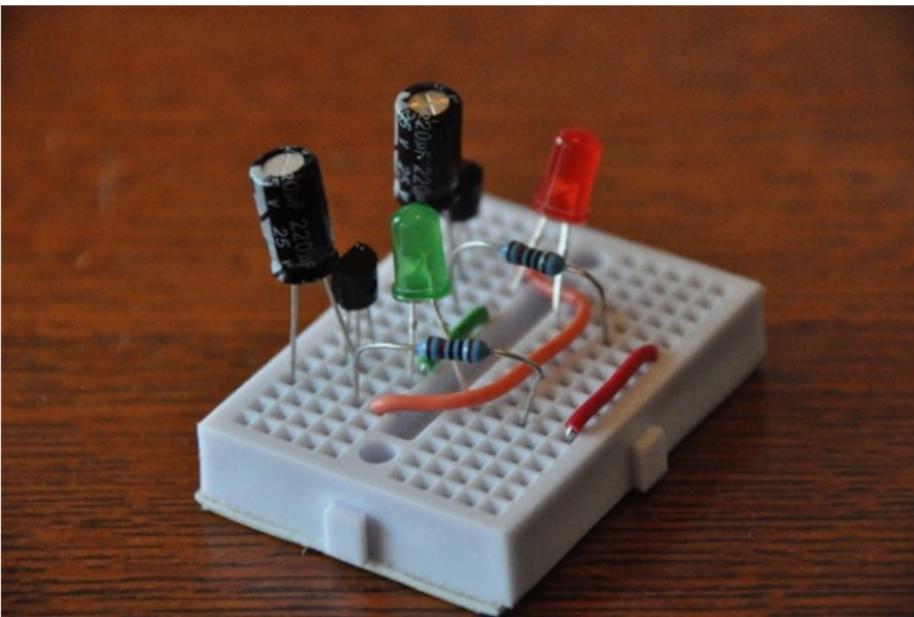
# Introduction



"THE CHANGING OF THE PASSWORDS  
HAS BECOME A DAILY EVENT."

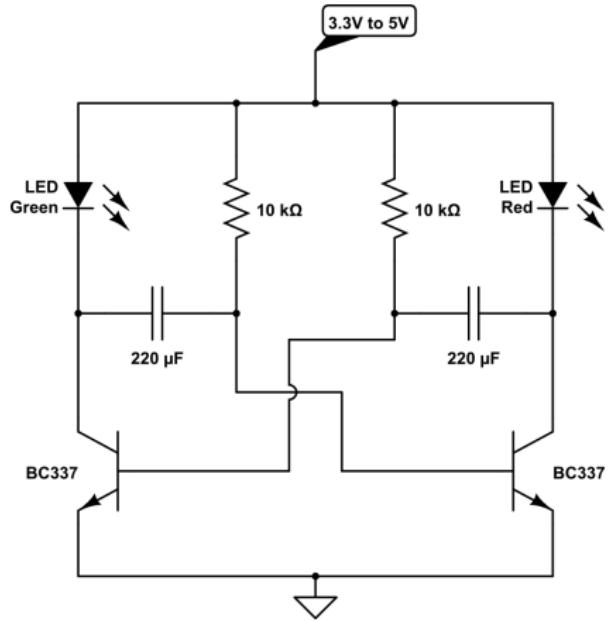


# Let's Build Something





# Oscillator: Flip Flop

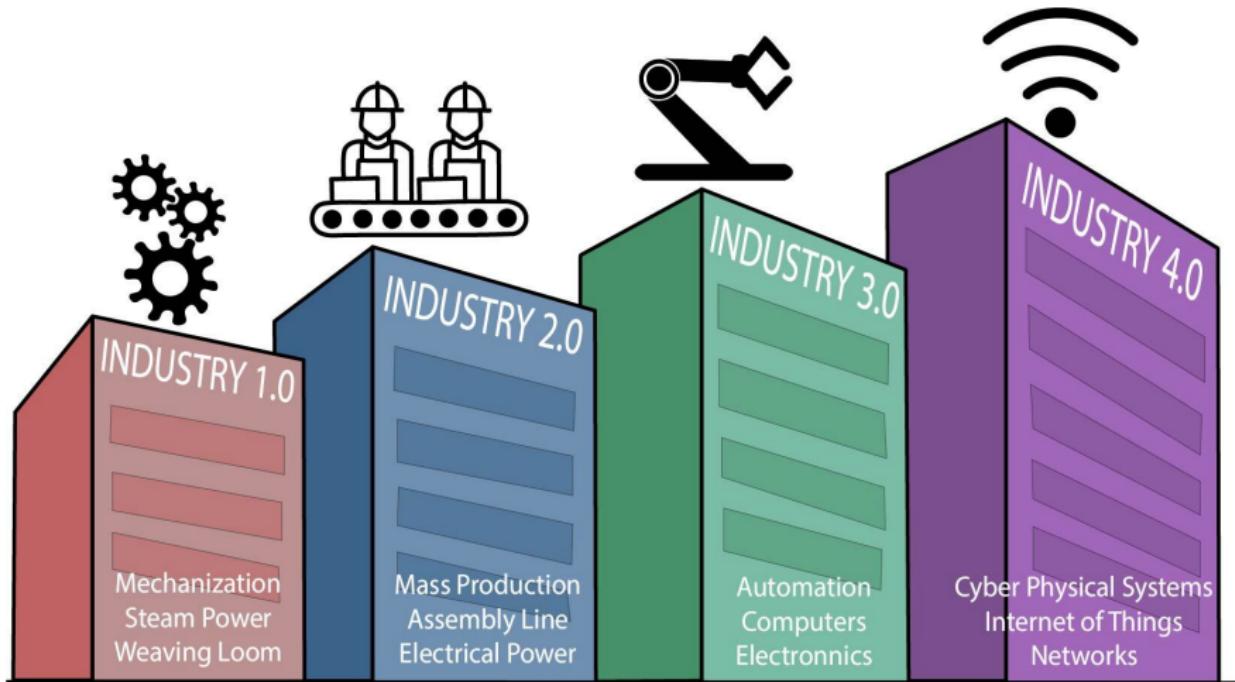


## Components:

- breadboard
- light emitting diode (LED)
- wires
- resistors
- capacitors
- transistors
- battery charge circuit

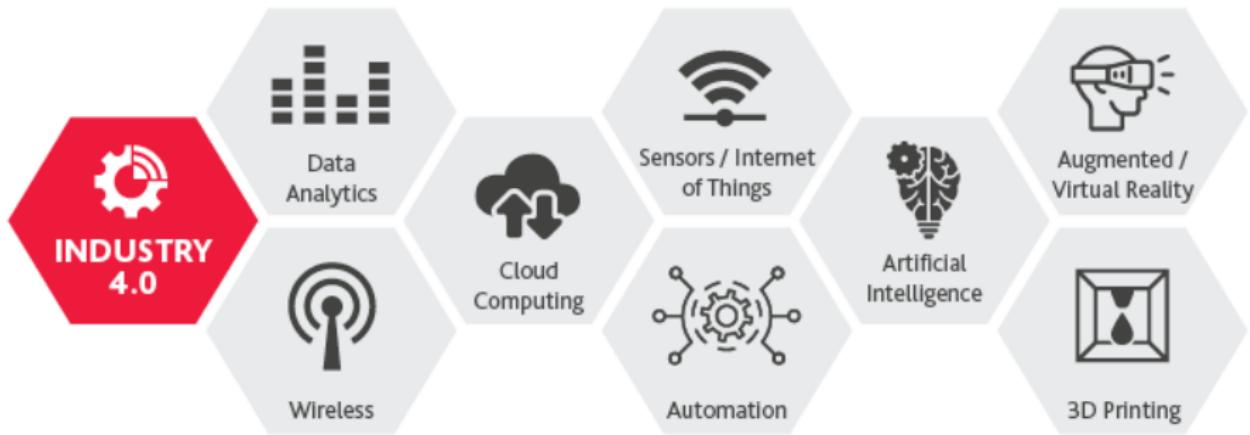


# Evolution of Industry



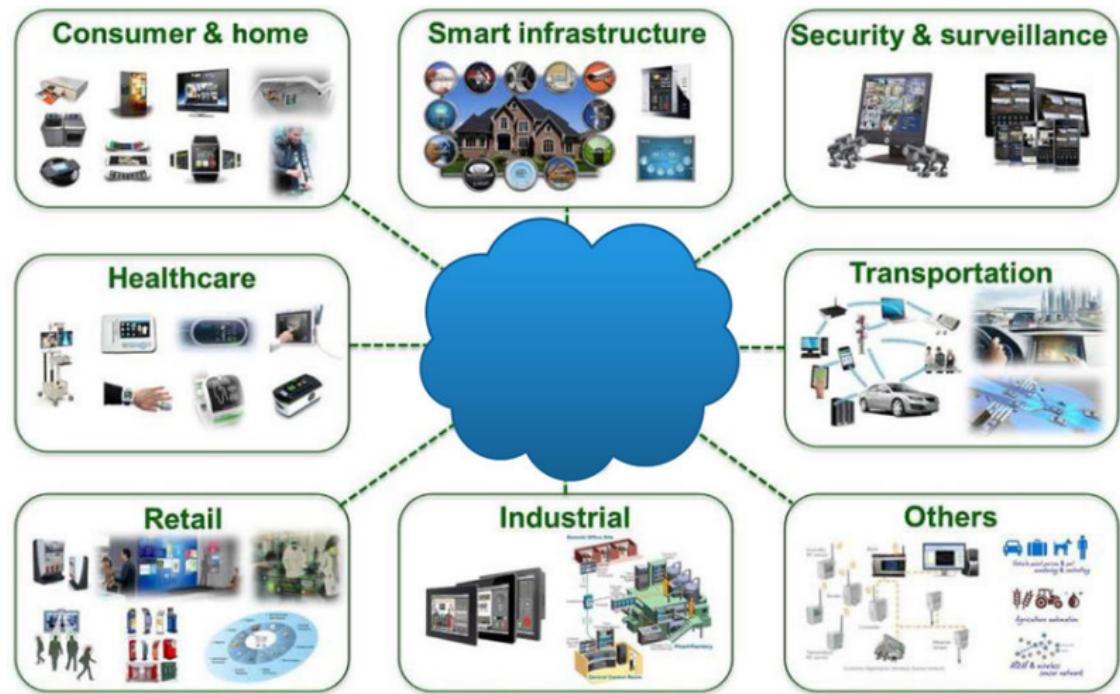


# Components of Industry 4.0



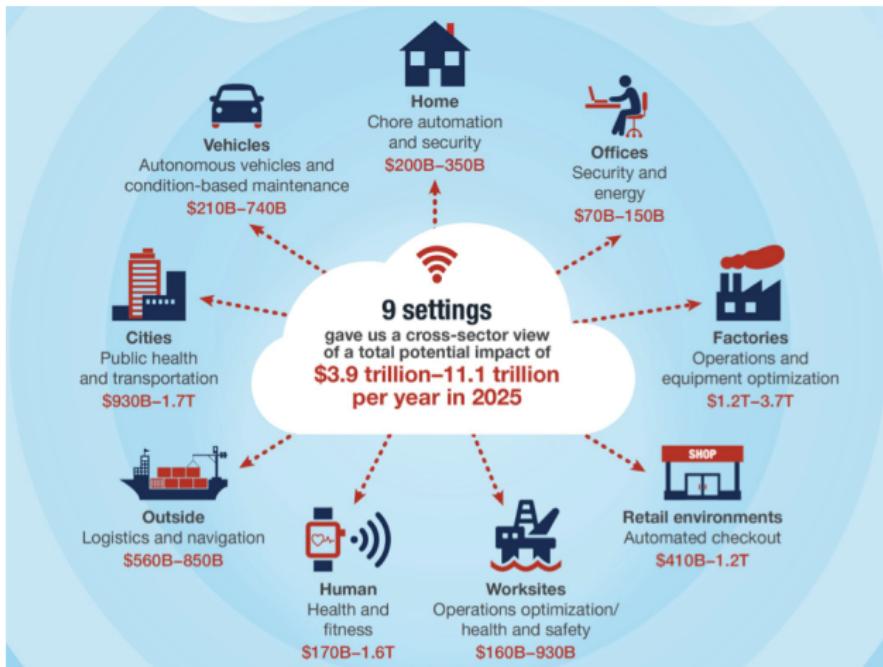


# What Is the Internet of Things





# IoT 2025





# Smart Facilities





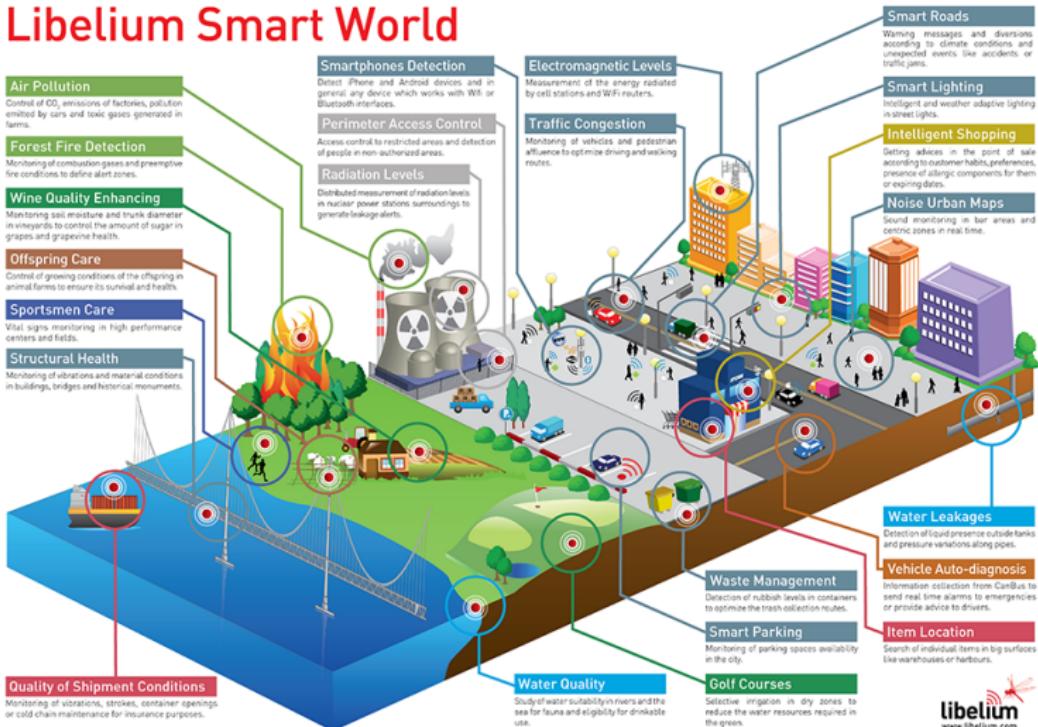
# Healthcare 2025





# Smart World

## Libelium Smart World





# And Out of This World





# IoT and Data Science



**AI:** Data-based learning



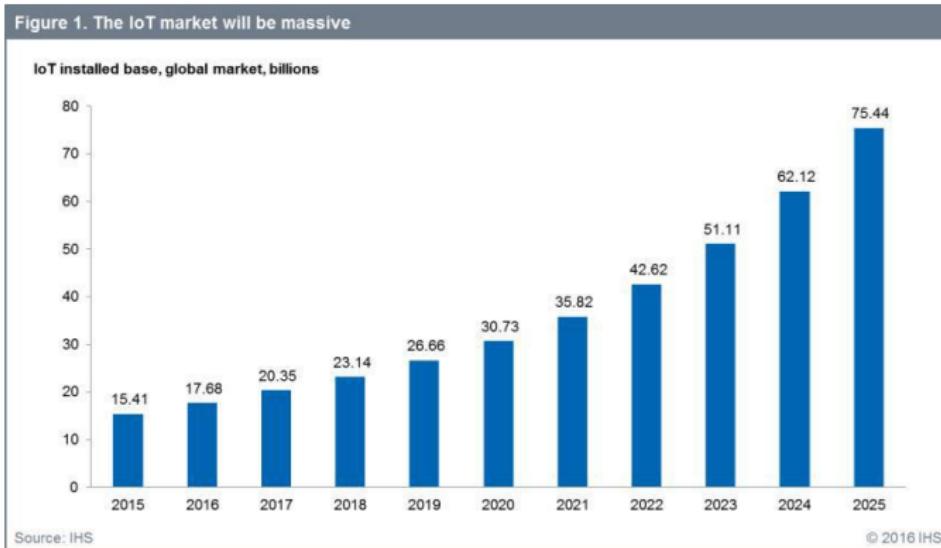
**Big Data:** Capture, storage, analysis of data



**IOT:** Data Collection through IoT



# How Big Will IoT Be



## How ubiquitous is the Internet of Things?

- There are approximately 31 billion IoT devices today.
- 127 new IoT devices are connected to the internet every SECOND.
- This morning, 1,828,800 IoT devices will be added to the internet.

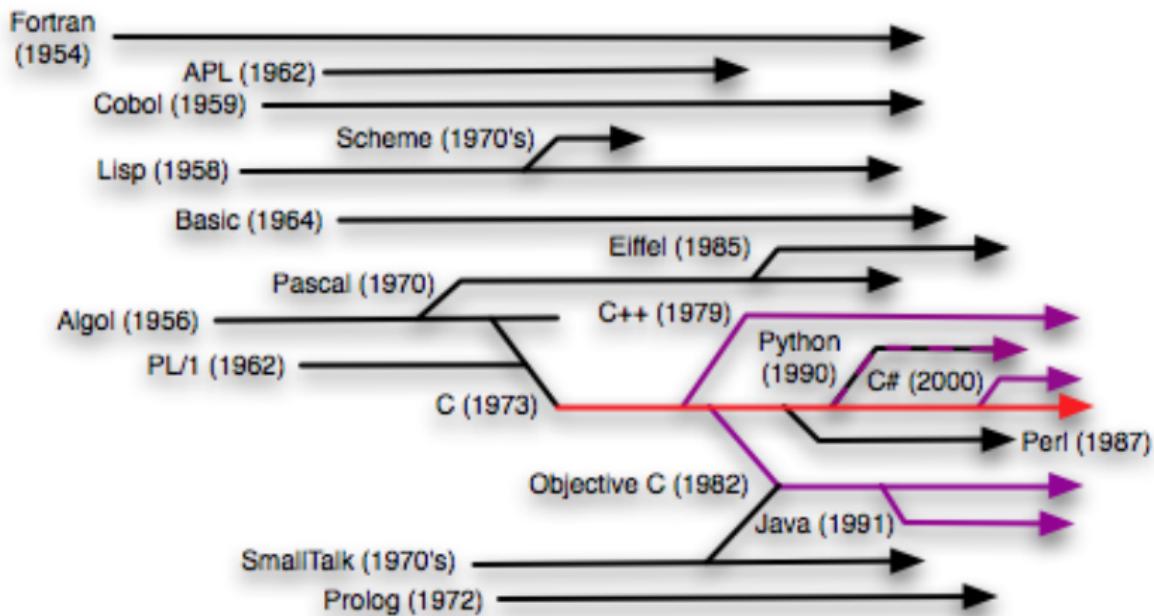


# Let's Begin Our Journey





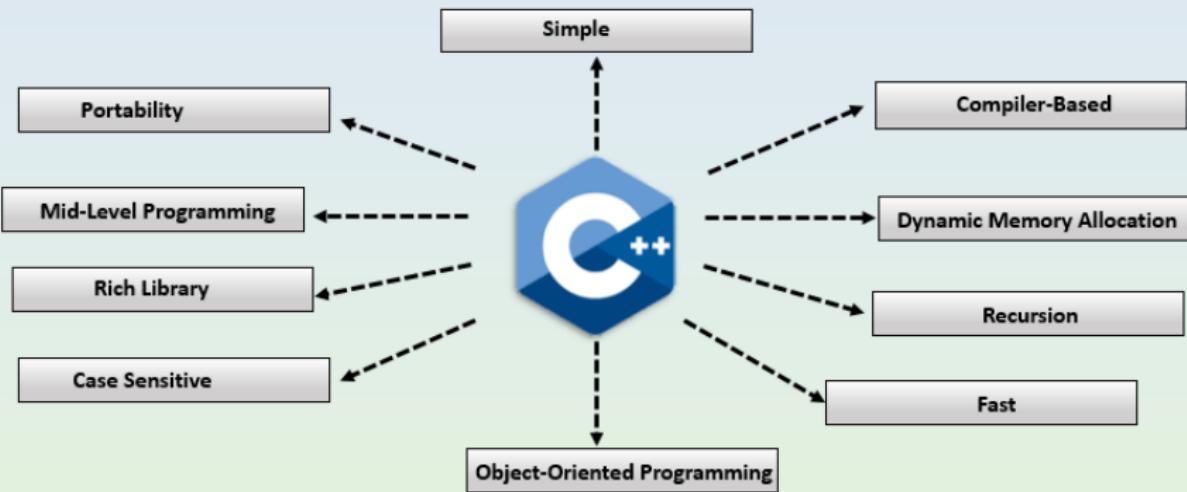
# Computer Languages





# Why C++

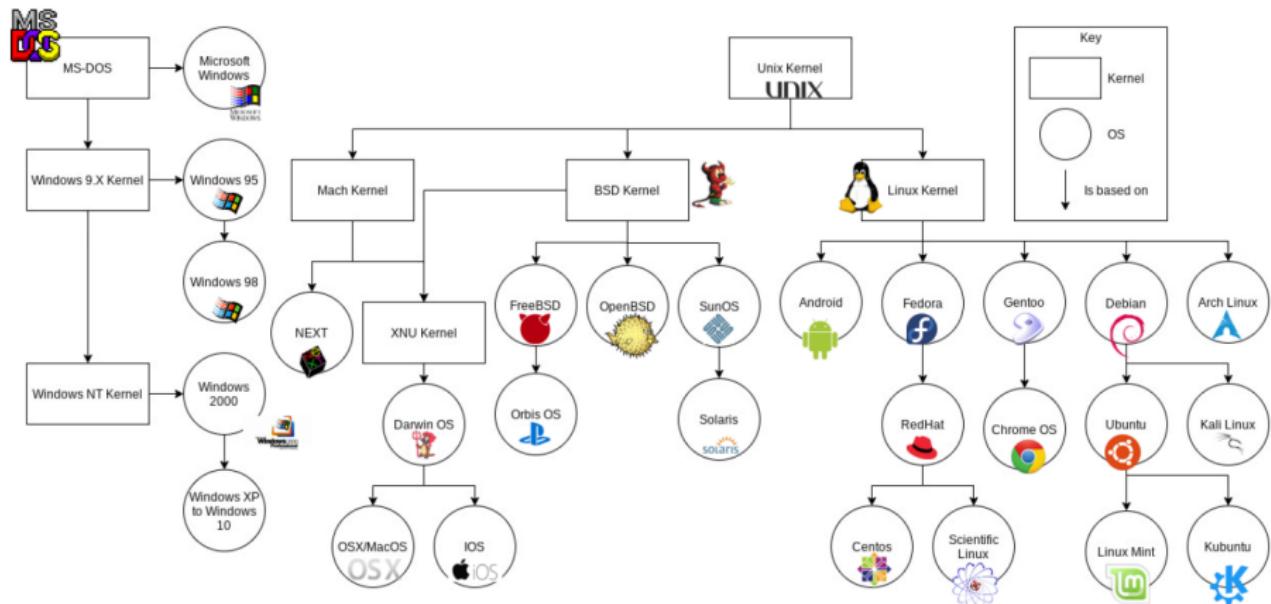
## Features of C++



[www.educba.com](http://www.educba.com)



# Operating Systems





# CLI vs GUI

```
[root@localhost ~]# cd /var  
[root@localhost var]# ls -la  
total 72  
drwxr-xr-x. 18 root root 4096 Jul 30 22:43 .  
drwxr-xr-x. 23 root root 4096 Sep 14 20:42 ..  
drwxr-xr-x. 2 root root 4096 May 14 00:15 account  
drwxr-xr-x. 11 root root 4096 Jul 31 22:26 cache  
drwxr-xr-x. 3 root root 4096 May 18 16:03 db  
drwxr-xr-x. 3 root root 4096 May 18 16:03 empty  
drwxr-xr-x. 2 root root 4096 May 18 16:03 games  
drwxrwx-T. 2 root gdm 4096 Jun 2 18:39 pdfs  
drwxr-xr-x. 38 root root 4096 May 18 16:03  
drwxr-xr-x. 2 root root 4096 May 18 16:03 log  
drwxr-xr-x. 2 root root 4096 May 18 16:03 private  
drwxr-xr-x. 2 root root 4096 Jul 1 22:11 repodata  
lrwxrwxrwx. 1 root root 6 May 14 00:12 run -> run  
drwxr-xr-x. 14 root root 4096 May 18 16:03 spool  
drwxrwxrwt. 4 root root 4096 Sep 12 23:58 tmp  
drwxr-xr-x. 2 root root 4096 May 18 16:03 yp  
[root@localhost var]# yum search wiki  
No matches found.  
[root@localhost var]#
```



# VS

Start





# Command Line Interface - Basic Navigation

The Command Line Interface (CLI) will allow us to directly navigate the computers operating system. We will use:

- macOS or Linux: Terminal
- Windows: PowerShell

The following commands will work on all three systems, except where noted below. macOS and Linux are case-sensitive, Windows is not.

- `pwd`: Show the present working directory.
- `ls`: To get the list of all the files or folders.
- `cd`: Used to change the directory.
- `du`: Show disk usage. (not available in PowerShell).
- `man`: Used to show the manual of any command.



# Command Line Interface - File and Directory Manipulation

- **mkdir:** Used to create a directory if it does not already exist. It accepts directory name as input parameter.
- **rmdir:** Used to delete a directory if it is empty.
- **cp:** This command will copy the files and directories from source path to destination path. It can copy a file/directory with a new name to the destination path. It accepts source file/directory and destination file/directory.
- **mv:** Used to move files or directories. This command is similar to the cp command but it deletes a copy of the file or directory from the source path.
- **rm:** Used to remove files or directories.
- **touch:** Used to create or update a file. (PowerShell New-Item).



# Command Line Interface - Displaying the file contents

- cat: It is generally used to concatenate files. It gives the output on the standard output.
- more: It is a filter for paging through text one screenful at a time.

The below commands are not available in PowerShell:

- less: Used for viewing files instead of opening the file. Similar to the "more" command but it allows backward as well as forward movement.
- head: Used to print the first N lines of a file. It accepts N as input and the default value of N is 10.
- tail: Used to print the last N-1 lines of a file. It accepts N as input and the default value of N is 10.

On all systems, commands can be "piped" together: ls | more <file>

# GitHub - Part 1



# Git and GitHub: Your Version Control Friends



# GitHub



# What is a version control system?

Version Control Systems (VCS) record changes made to files so that you can

- compare and track changes over time
- revert single files to a previous state
- revert an entire project to an earlier version

Git is a VCS, or Version Control System.

It is similar to Backup on Windows or Time Machine on the Mac.



# Installing Git

Windows:

- <https://git-scm.com/download/win>

Mac

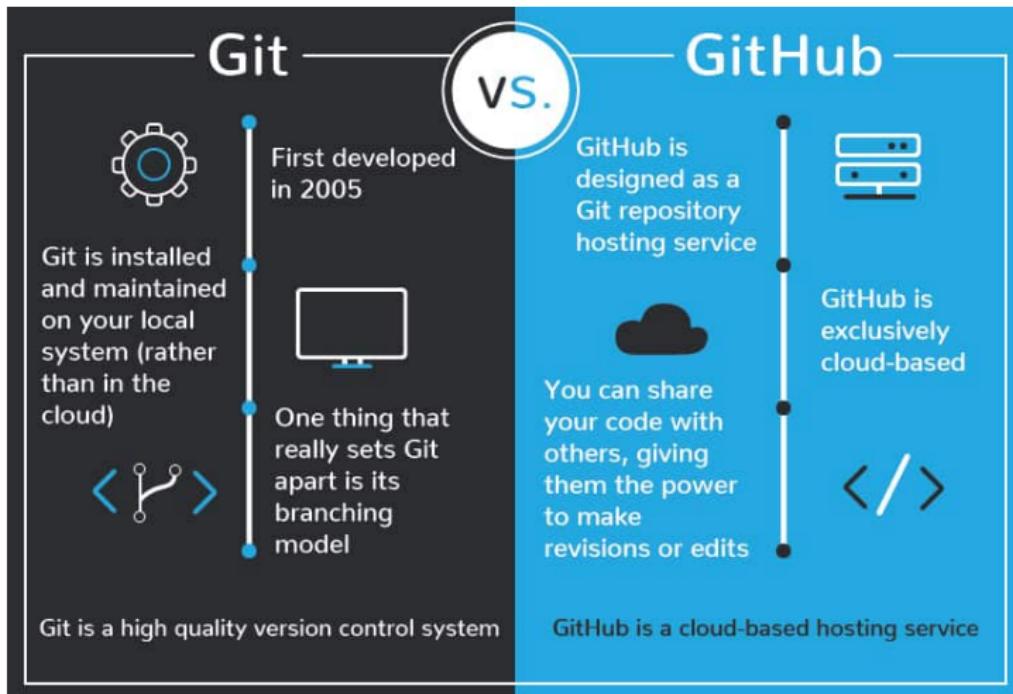
```
1 # install homebrew
2 /bin/bash -c "$(curl -fsSL https://raw.githubusercontent.com/Homebrew/install/HEAD/
   install.sh)"
3
4 # might be necessary on M1/M2 Macs
5 eval $(/opt/homebrew/bin/brew shellenv)
6
7 # install git
8 brew install git
```

Linux

```
1 sudo apt-get install git-all
```



# Git vs. GitHub





# Commit vs. Push

To save files to your **LOCAL** repository, use the *commit* command. The file is given a timestamp and a unique commit number that is the file version.

→ git commit

To save a file to your **REMOTE** GitHub repository, use the *push* command.

→ git push

**Remember to Push your files** in order to save from data loss and to ensure your work is available for collaboration.



# When should you commit and push your work?

When to commit? **OFTEN!**

- Any time you finish a task where you want to save or retain a version.

When to push? **OFTEN!**

- Any time you have finished a task, milestone, or significant project.
- At the end of each work session
  - Before you take a break
  - Before a meeting
  - Before lunch
  - Before you go offline for the day



# Getting a GitHub account

If you do not already have a GitHub account, you will want to create one.

- ① Go to <https://github.com>
- ② Click Sign Up.
- ③ Type a unique username and password for your account.
  - *Note: you should consider a user name that is professional if you plan to share your GitHub account with prospective employers as part of your work portfolio.*
- ④ Complete the sign up process and Create Account.



# GitHub Authentication: Using HTTPS and PAT

Effective August 2021, account passwords will no longer be allowed for command line GitHub access. Instead, you must create a Personal Access Token (PAT) to use in place of a less secure password.

To create a PAT:

- ① Login to your GitHub account.
- ② Click your account icon.
- ③ Click the Settings menu option.
- ④ Click Developer Settings.
- ⑤ Click Personal access tokens.
- ⑥ Generate a new token for GitHub Command Line Access.
- ⑦ Check the repo option.
- ⑧ Click Generate Token.

Now when you login to GitHub on the command line, use your PAT rather than your password to access your account.



# GitHub: Cloning and Pulling Code

To get an existing GitHub repository, you will clone it to your local system.

**git clone <URL of repository>**

Let's get the Class Slide now, from your IoT directory:

```
1 git clone https://github.com/ddc-iot/class_materials
```

To get updates from a GitHub repository after you have already cloned it to your local system, you will pull the code.

**git pull**

*Note: make sure you are in the repository folder before doing a git pull.*



# GitHub: Getting Assignments

ddc-iot-classroom-2

Accept the assignment —

L01\_HelloWorld

Once you accept this assignment, you will be granted access to the `l01-helloworld-brashap` repository in the `ddc-iot` organization on GitHub.



You're ready to go!

You accepted the assignment, L01\_HelloWorld.

Your assignment repository has been created:



<https://github.com/ddc-iot/l01-helloworld-brashap>

```
1 brian:~$ cd Documents/
2 brian:Documents$ mkdir IoT
3 brian:Documents$ cd IoT
4 brian:IoT$ git clone https://github.com/ddc-iot/L01_helloWorld-brashap
5 Cloning into 'L01_helloWorld'...
6 Username for 'https://github.com': brashap
7 Password for 'https://brashap@github.com':
8 remote: Enumerating objects: 4, done.
9 remote: Counting objects: 100% (4/4), done.
10 remote: Compressing objects: 100% (3/3), done.
11 remote: Total 4 (delta 0), reused 4 (delta 0), pack-reused 0
12 Unpacking objects: 100% (4/4), 321 bytes | 53.00 KiB/s, done.
```



# GitHub: Cheatsheet. Memorize this!

```
1 // In PowerShell go to ./Documents/IoT
2 // Get a repository that already exists and pull
   it into your local machine
3 git clone <URL of repository>
4
5 // Send your changes up to the repository
6 git add . //adds all changed files
7 git commit -m "some comment"
8 git push //send your changes to the cloud
9
10 // The first time you use git, you may get asked
    to enter your GIT username
11 git config --global user.email "you@example.com"
12
13 // From the repository directory, get updates
14 git pull
```



# Other Software

## ① Fritzing

- IoT Bootcamp Teams Site
- Note: to extract faster, <https://www.7-zip.org/download.html>

## ② KiCad

- <https://www.kicad.org/download/>

## ③ Drawio

- <https://app.diagrams.net/>

## ④ Adobe Illustrator

- <https://www.adobe.com/creativecloud.html>

## ⑤ Formlab's Preform

- <https://formlabs.com/software/>

## ⑥ Ultimaker's Cura

- <https://ultimaker.com/software/ultimaker-cura>

## ⑦ Bookmark: <https://www.desmos.com/>



# Solidworks

To install Solidworks (Windows only), go to

<http://www.SolidWorks.com/SEK>

- Enter your contact information.
- Check the radio button “Yes” under ”I already have a Serial Number that starts with 9020”.
- Select the version and click Request Download.
- On the next page, Accept the agreement and continue.
- On the final page, click the Download button to download the SolidWorks Installation Manager.
- Unzip the files to launch the Installation.
- Select the option for Individual/On this machine.
- Install using the following serial number provided by your instructor.

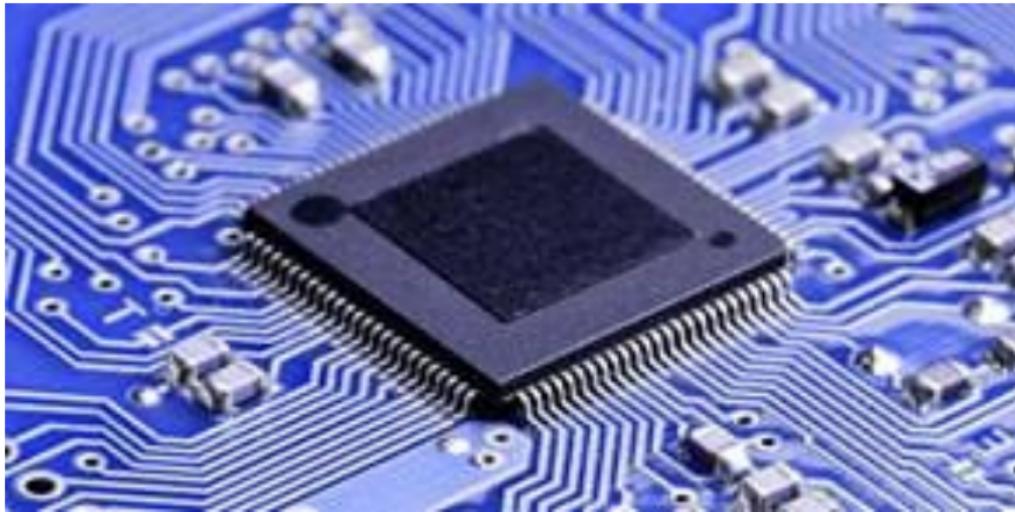
macOS and Linux users will use onShape:

<https://www.onshape.com/en/education/>

# Particle Argon

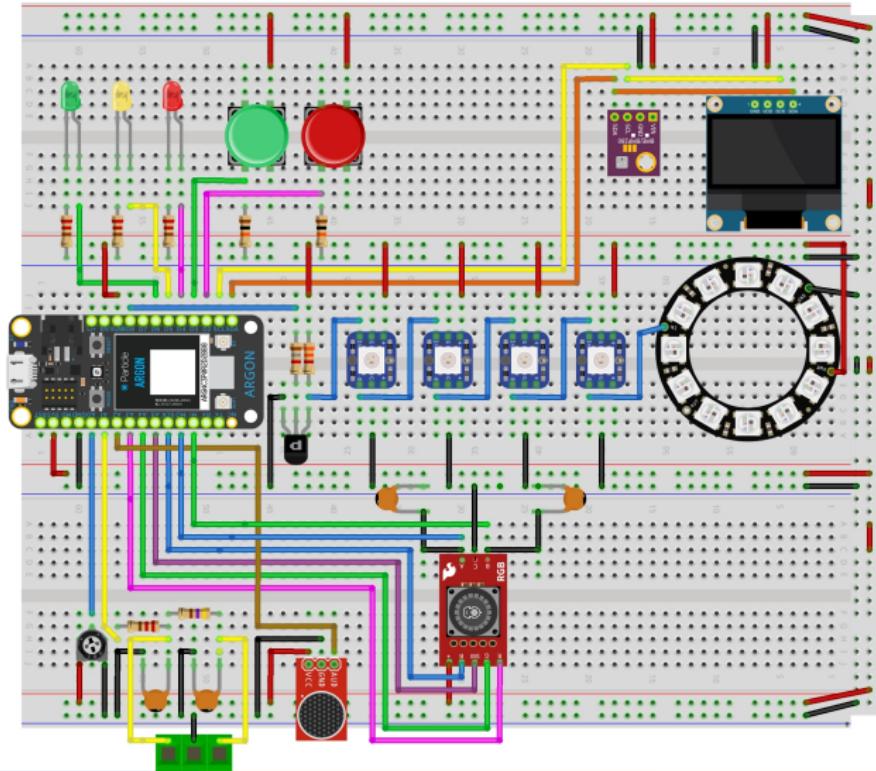


# Our Microcontroller



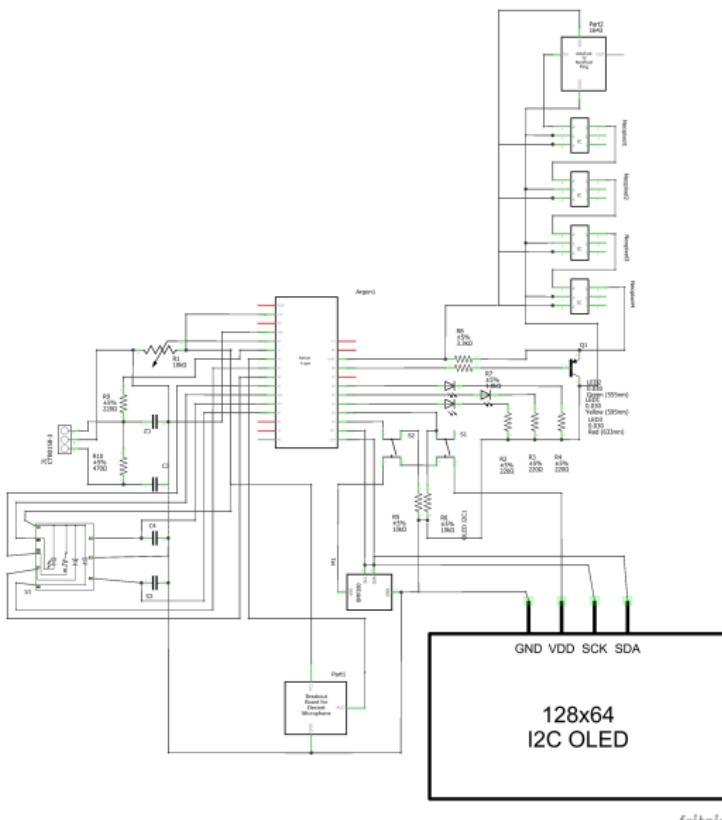


# Smart Room Controller





# Smart Room Controller Schematic





# Particle Argon

## Main processor:

Nordic Semiconductor nRF52840 SoC

- ARM Cortex-M4F 32-bit processor @ 64MHz
- 1MB flash, 256KB RAM
- Bluetooth LE (BLE) central and peripheral support
- 20 mixed signal GPIO (6 x Analog, 8 x PWM), UART, I2C, SPI
- Supports DSP instructions, HW accelerated Floating Point Unit (FPU) calculations
- ARM TrustZone CryptoCell-310 Cryptographic and security module
- Up to +8 dBm TX power (down to -20 dBm in 4 dB steps)
- NFC-A radio

## Argon Wi-Fi network coprocessor:

Espressif ESP32-D0WD 2.4 GHz Wi-Fi coprocessor

- On-board 4MB flash for the ESP32
- 802.11 b/g/n support
- 802.11 n (2.4 GHz), up to 150 Mbps

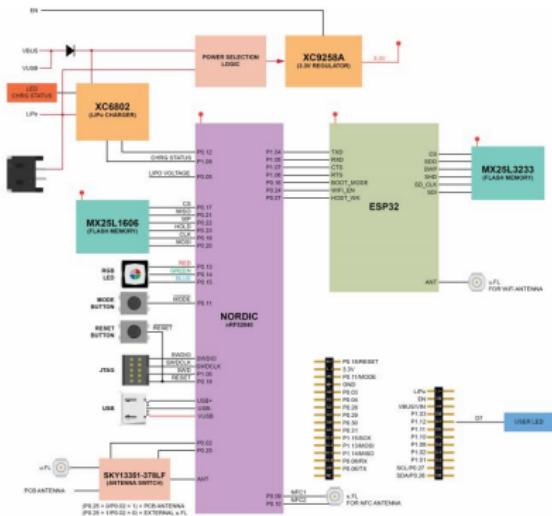


## Argon general specifications:

- On-board additional 4MB SPI flash
- Micro USB 2.0 full speed (12 Mbps)
- Integrated Li-Po charging and battery connector
- JTAG (SWD) Connector
- RGB status LED
- Reset and Mode buttons
- On-board 2.4GHz PCB antenna for Bluetooth (does not support Wi-Fi)
- Two U.FL connectors for external antennas (one for Bluetooth, another for Wi-Fi)
- Meets the [Feather specification](#) in dimensions and pinout
- FCC, CE and IC certified
- RoHS compliant (lead-free)



## Particle Argon Block Diagram

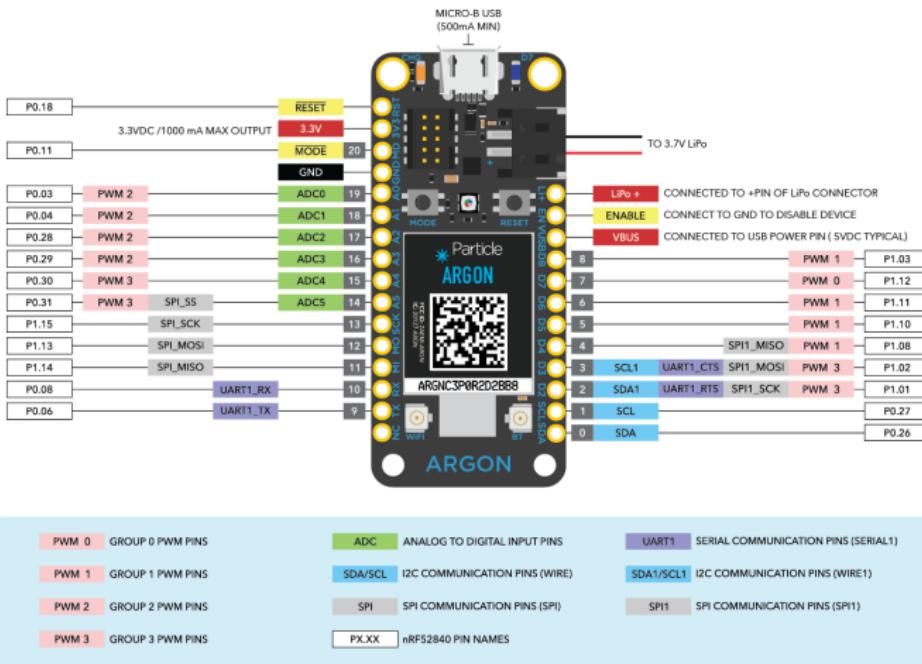


- nRF52840 (64 MHz ARM M4 Cortex with BLE and NFC)
  - ESP32 (Wifi Coprocessor)
  - 20 GPIO pins
  - Additional 4MB SPI Flash
  - Integrated LiPo battery charging
  - Adafruit Feather pinout



# Argon Pinout

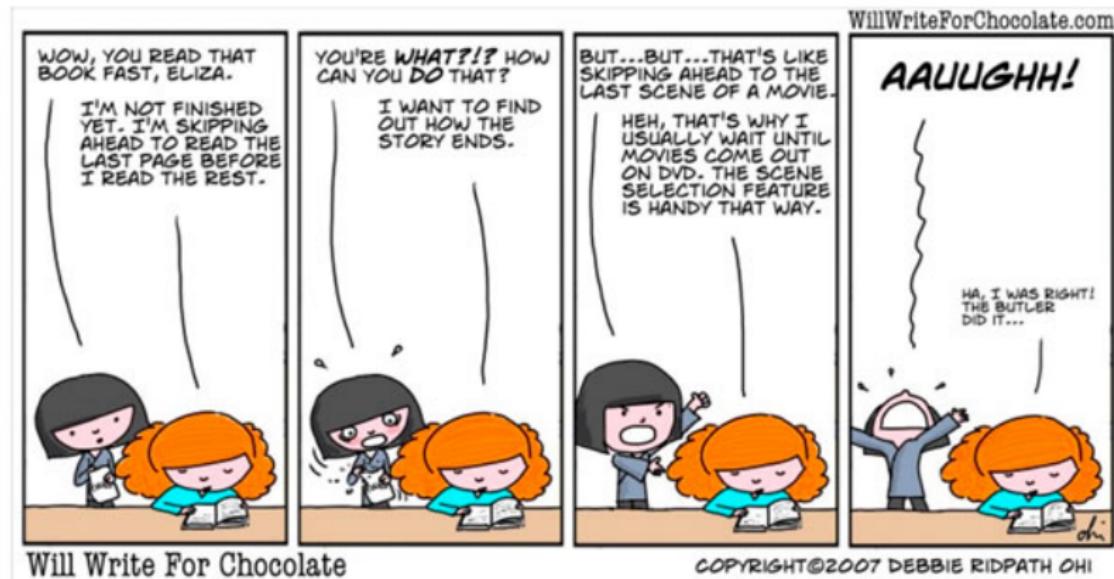
 Particle



v1.0



# Please Do Not Skip Ahead During Setup





# If you have a Mac M1/M2 (Apple Silicon)

Terminal needs to be “Open using Rosetta” option:



<https://www.courier.com/blog/tips-and-tricks-to-setup-your-apple-m1-for-development/>



# Installing Particle CLI

Windows:

- <https://docs.particle.io/tutorials/developer-tools/cli/>

Mac

```
1 # install the CLI
2 bash <( curl -sL https://particle.io/install-cli )
3
4 # might be necessary on M1/M2 Macs
5 eval $(/opt/homebrew/bin/brew shellenv)
6
7 # install the DFU-util, a utility program for programming devices over USB
8 arch -arm64 brew install dfu-util
```

Linux

```
1 # install the CLI
2 bash <( curl -sL https://particle.io/install-cli )
3
4 # install the DFU-util, a utility program for programming devices over USB
5 sudo apt-get install dfu-util
```

- Test that the Particle CLI installed correctly by going to PowerShell or Terminal and type particle.



# Particle Software - Visual Studio Code

- ① Create Particle login: <https://login.particle.io/signup>
- ② Download Particle Workbench / Visual Studio Code  
[https://docs.particle.io/quickstart/workbench/.](https://docs.particle.io/quickstart/workbench/)
  - Select all default values during install.
  - **Do NOT install Azure IoT.**
  - After it is installed, when you launch it, it may ask you to Install Dependencies. If so, select yes.



# Particle Setup

- ① Attach the Wi-Fi antenna to your Argon. Use the correct connector. There are 3 U.FL connectors: WiFi, BT, and NFC.
- ② Plug the Argon into a USB port. It should begin blinking blue.
- ③ Open PowerShell or Terminal.
- ④ Login into your Particle Account.

```
1 particle login
```

- ⑤ Ensure you have the latest Particle CLI.

```
1 particle update-cli
```

- ⑥ Put the Argon in DFU mode (blinking yellow) by holding down MODE. Tap RESET and continue to hold down MODE. The status LED will blink magenta (red and blue at the same time), then yellow. Release when it is blinking yellow.



# Updating your Argon to latest Device OS

- ① Update the device by running the following two commands. If the device goes out of blinking yellow after the first command, put it back into DFU mode. See Note <sup>4</sup>.

```
1 particle update  
2 particle flash --usb tinker
```

- ② When the command reports Flash success!, reset the Argon. It should go back into listening mode (blinking dark blue).
- ③ Verify that the update worked by running the following command:

```
1 particle serial identify  
2  
3 Your device id is e00fce681ffffffffc08949b  
4 Your system firmware version is 1.5.2
```

---

<sup>4</sup>particle flash –usb tinker can be used for device troubleshooting



# Setting Up WiFi

- Set your Argon into Listening Mode by holding the MODE button for three seconds, until the RGB LED begins blinking blue.
- Execute the command: `particle serial wifi`

```
brian:~$ particle serial wifi
? Should I scan for nearby Wi-Fi networks? No
? SSID DDCIOT
? Security Type WPA2
? Cipher Type AES+TKIP
? Wi-Fi Password ddcIOT2020
Done! Your device should now restart.
```

After setting, your Argon should go through the normal sequence of blinking green, blinking cyan (light blue), fast blinking cyan, and breathing cyan.



# Claim Your Device

- ① Claim the device to your account. This can only be done if it's breathing cyan. Replace e00fce681ffffffffc08949b with the device ID you got earlier from particle serial identify. Then, rename it to the name of your choice.

```
1 particle device add e00fce681fffffffffc08949b  
2 particle device rename e00fce681fffffffffc08949b  
      myArgon
```

- ② Ensure that your setup flag is marked as done.

```
1 particle usb setup -done
```

- ③ You have successfully set up your Argon!



# Useful Particle CLI Commands

- ① Enter DFU mode from the CLI.

```
1 particle usb dfu
```

- ② If the Argon won't enter DFU mode or is otherwise acting strangely, restore the base firmware.

```
1 particle flash --usb tinker
```

- ③ Get a list of your Particle devices and their connection status.

```
1 particle list
```

- ④ Search for available libraries.

```
1 particle library search <search term>
```

- ⑤ Link for the Particle Setup procedures: [Particle Setup via CLI](#)



# Particle Troubleshooting

- ① Enter DFU mode from the CLI.

```
1 particle usb configure
```



# Argon LED Modes

| Mode                          | LED Status  |
|-------------------------------|---|
| Connected                     | Breathing Cyan                                      |
| OTA Firmware Update           | Blinking Magenta (red and blue together)            |
| Looking for Internet          | Blinking Green                                      |
| Connecting to Cloud           | Rapid Blinking Cyan                                 |
| Listening Mode                | Blinking Blue                                       |
| Network Reset                 | Rapid Blinking Blue                                 |
| WiFi Off                      | Breathing White                                     |
| Safe Mode                     | Breathing Magenta (red and blue together)           |
| DFU (Device Firmware Upgrade) | Blinking Yellow                                     |
| Restore Factory Firmware      | Rapid Blinking Yellow                               |
| Factory Reset                 | Rapid Blinking White                                |
| Decryption Error              | Blinking Cyan followed by 1 Orange Blink            |
| No Internet                   | Blinking Cyan followed by 2 Orange Blink            |
| No Particle Cloud             | Blinking Cyan followed by 3 Orange Blink            |
| Authentication Error          | Blinking Cyan followed by 1 Magenta Blink           |
| Handshake Error               | Blinking Cyan followed by 1 Red Blink               |
| Decryption Error              | Blinking Cyan followed by 1 Orange Blink            |
| SOS - Firmware Crash          | Blinking Red - 3 short, 3 long, 3 short, error code |



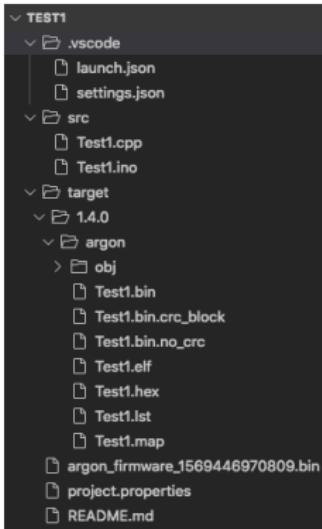
# Directory Structure - VERY IMPORTANT

The screenshot shows the VS Code interface with the following details:

- EXPLORER** view: Shows the project structure:
  - OPEN EDITORS**: 1 UNSAVED
  - PM25\_Testino** (selected)
  - PM25\_TEST**:
    - .vscode
    - launch.json
    - settings.json
  - lib\Seeed\_HM330X**:
    - examples\basic\_demo
    - basic\_demo.ino
  - src**:
    - HM330XErrorCode.h
    - I2COperations.cpp
    - I2COperations.h
    - Seeed\_HM330X.cpp
    - Seeed\_HM330X.h
  - PM25**:
    - PM25.cpp
    - PM25.h
  - target\1.5.0\argon**
  - project.properties**
  - README.md**
- CODE** view: Displays the content of **PM25\_Testino\src\PM25\_Testino.ino**. The code includes headers for Particle, Seeed\_HM330X, and Wire, and defines a class PM25 with methods for printing sensor data and serial output.



# Directory Structure - VERY IMPORTANT



- The .vscode directory contains your project-specific settings.
- The src directory contains your source file. The .ino file is transformed into a .cpp before compiling.
- Not pictured here is the lib directory, at the same level as src. This contains the source to libraries that you have included.
- The target directory contains local build output
- The \*.bin file is the result of a cloud compile for this project.
- The project.properties file specifies all of the libraries that this project uses.
- README.md is where you could put documentation for your project.



# Command Palette - Ctrl-Shift-P

>particle

- Particle: Install Library** recently used
- Particle: Find Libraries**
- Particle: Cloud Compile**
- Particle: Configure Workspace for Device**
- Particle: Launch CLI**
- Particle: Install Local Compiler**
- Particle: Cloud Flash**
- Particle: Serial Monitor**
- Particle: Create New Project**
- Particle: Audit Environment**
- Particle: Who Am I?**
- **Particle: Clean application (local)** other commands
- Particle: Clean application & DeviceOS (local)**



# Improve Compile Time

Anti-virus programs scan everything that VSCode is doing. This leads to long compile times. To reduce the compile times, you can exclude your particle code from real-time virus scans.

## Manage exceptions

Add or remove items to be excepted from scan.

+ Add an Exception

| All exceptions               | Antivirus                              | Advanced Threat Defense |
|------------------------------|--|-------------------------|
| c:\users\ddcio\particle      | On-access, On-demand, Embedded scripts |                         |
| c:\users\ddcio\vscode        | On-access, On-demand, Embedded scripts |                         |
| c:\users\ddcio\documents\iot | On-access, On-demand, Embedded scripts |                         |



Go to Start > Settings > Update & Security > Windows Security > Virus & threat protection. Under Virus & threat protection settings, select Manage settings, and then under Exclusions, select Add or remove exclusions. Select Add an exclusion, and then select from files, folders, file types, or process.



Bitdefender

How to exclude files and folders from Bitdefender Antivirus scan

1. Click Protection on the navigation menu on the Bitdefender interface.
2. In the ANTIVIRUS pane, click Open.
3. In the Settings window, click Manage Exceptions.
4. Click +Add an Exception.

To set a global exception:

1. Open AVG AntiVirus and go to ≡ Menu ▶ Settings.
2. Select General ▶ Exceptions, then click Add exception.
3. Add an exception in one of the following ways: Type the specific file/folder path or URL into the text box, then click Add exception.



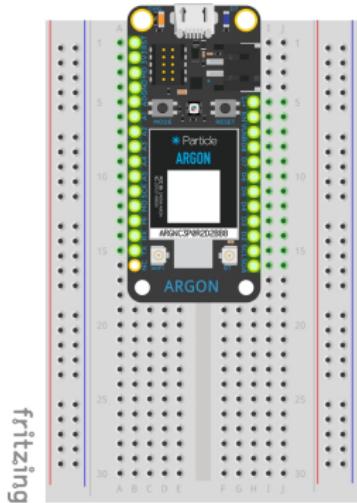
1. Open your McAfee security software.
2. Click PC Security.
3. Click Real-Time Scanning.
4. Click Excluded Files.
5. Click Add file.
6. Browse to, and select, the file that you want to exclude from Real-Time scanning.



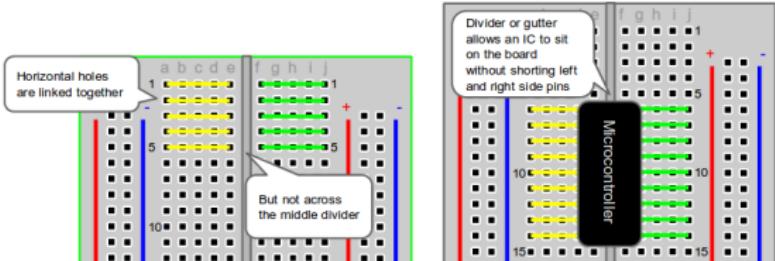
# Module 1 - HelloWorld



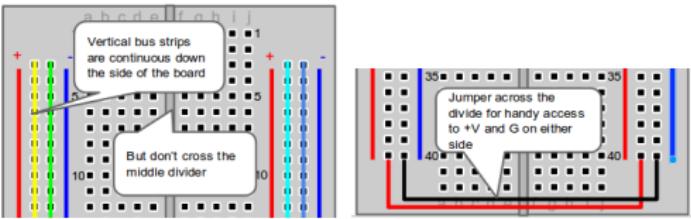
# Argon on Breadboard



## Horizontal Rows



## Vertical Columns





# Basic Structure of Arduino Sketch

```
1 // the "header" is used for GLOBALS
2
3 void setup() {
4     // code in setup() runs once
5     // it is used to initialize objects,
6     // begin processes, and set variables
7     pinMode(13, OUTPUT);    //set Pin 13 as an Output
8 }
9
10 void loop() {
11     // functionality of your code
12     // this loops indefinitely
13 }
```



# Class Assignments

- ① Lab Notebook - flow chart
- ② Lab Notebook - schematic
- ③ Fritzing breadboard layout
- ④ Arduino code with comments

```
1 /*
2  * Project:      Title of Project
3  * Description: Description of Project
4  * Author:       Your Name
5  * Date:        Today's Date
6 */
7
8 // Single Line Comments
```



# Hello World in some of the 603+ Coding Languages

## Fortran

```
c      Hello world in Fortran
      PROGRAM HELLO
      WRITE (*,100)
      STOP
100 FORMAT (' Hello world! ' /)
      END
```

## C (K&R)

```
/* Hello world in c, K&R-style */
main()
{
    puts("Hello world!");
    return 0;
}
```

## Python 2

```
# Hello world in python_2
print "Hello world"
```

## Assembler (Intel)

```
; Hello world for intel Assembler (MSDOS)
mov ax,cs
mov ds,ax
mov ah,9
mov dx, offset Hello
int 21h
xor ax,ax
int 21h
```

```
Hello:
db "Hello world!",13,10,"$"
```

## Powershell

```
# Hello World in Microsoft Powershell
'Hello world!'
```

## LabVIEW

Hello world in LabVIEW 7.1

## LaTeX

```
% Hello world! in LaTeX
\documentclass{article}
\begin{document}
Hello world!
\end{document}
```

## Unix Shell

```
# Hello world for the unix_shells (sh, ksh, csh, zsh, bash, fish, xonsh, ...)
echo Hello world
```

## Lisp-Emacs

```
(defun hello-world()
  "Display the string hello world."
  (interactive)
  (message "hello world"))
```

## BASIC

```
10 REM Hello world in BASIC
20 PRINT "Hello world!"
```

## C++

```
// Hello world in C++ (pre-ISO)
#include <iostream.h>
main()
{
    cout << "Hello world!" << endl;
    return 0;
}
```

## Perl

```
# Hello world in perl
print "Hello world!\n";
```

## Python 3

```
# Hello world in Python_3
print("Hello world")
```

## Pascal

```
{Hello world in pascal}
program Helloworld(output);
begin
    writeln('Hello world!');
end.
```

## MATLAB

```
% Hello world in MATLAB.
disp('Hello world');
```

## HTML

```
<HTML>
<!-- Hello world in HTML -->
<HEAD>
<TITLE>Hello world!</TITLE>
</HEAD>
<BODY>
Hello world!
</BODY>
</HTML>
```

## Postscript

```
% Hello World in Postscript
%PS
/Palatino-Roman findfont
100 scalefont
setFont
100 100 moveto
(Hello world!) show
showpage
```



# Assignment L01\_01\_HelloWorld



We will write our first program together as a class, using:

- `pinMode(pin,mode)`
- `digitalWrite(pin,state)`
- `delay(delay_time)`

How fast can you make it blink and still see it blinking?



# Other Software

## ① Git

- For Windows - <https://git-scm.com/download/win>
- For Mac - <https://git-scm.com/download/mac>
- For Linux - sudo apt-get install git-all

## ② Fritzing

- IoT Bootcamp Teams Site
- Note: to extract faster, <https://www.7-zip.org/download.html>

## ③ Drawio

- <https://app.diagrams.net/>

## ④ Adobe Illustrator

- <https://www.adobe.com/creativecloud.html>

## ⑤ Formlab's Preform

- <https://formlabs.com/software/>

## ⑥ Ultimaker's Cura

- <https://ultimaker.com/software/ultimaker-cura>

## ⑦ Bookmark: <https://www.desmos.com/>



# Solidworks

To install Solidworks (Windows only), go to

<http://www.SolidWorks.com/SEK>

- Enter your contact information.
- Check the radio button "Yes" under "I already have a Serial Number that starts with 9020".
- Select the version and click Request Download.
- On the next page, Accept the agreement and continue.
- On the final page, click the Download button to download the SolidWorks Installation Manager.
- Unzip the files to launch the Installation.
- Select the option for Individual/On this machine.
- Install using the following serial number provided by your instructor.

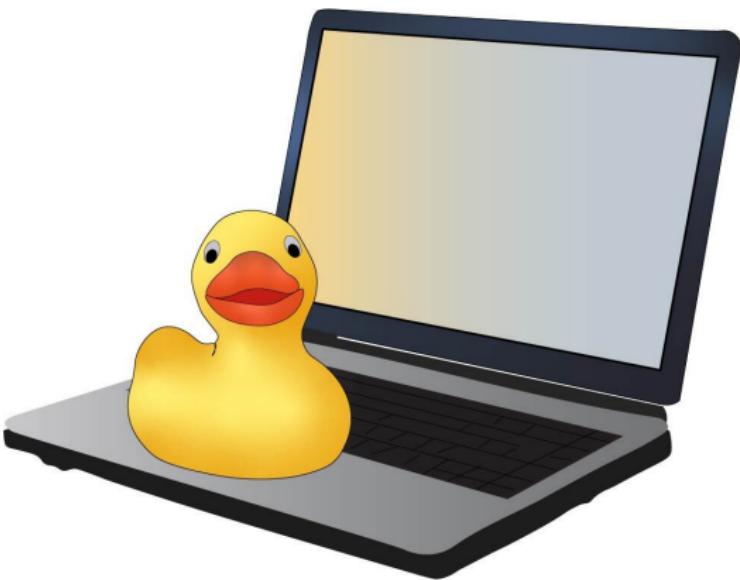
macOS and Linux users will use onShape:

<https://www.onshape.com/en/education/>

## Module 2 - HelloLED



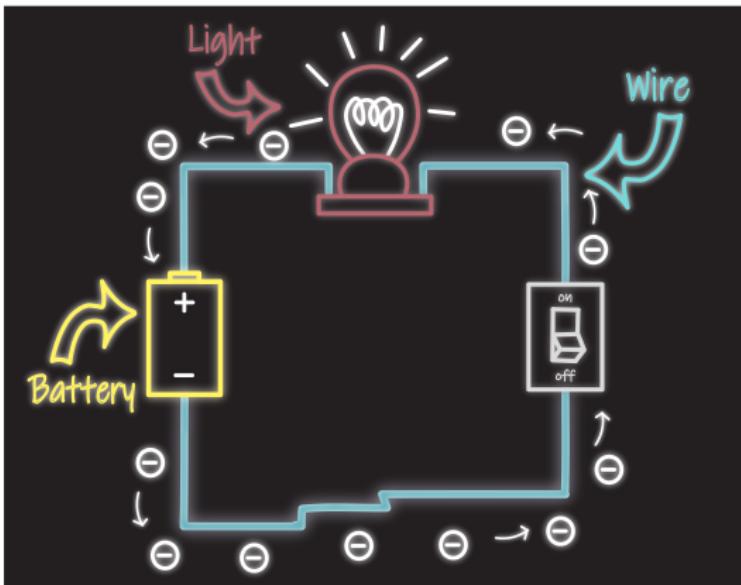
# Rubber Ducking - An Odd but Brilliant Tool



Rubber ducking is simply a method of debugging code. Programmers carry around a rubber duck with them, When they get stuck, they explain their code line-by-line to the rubber duck.

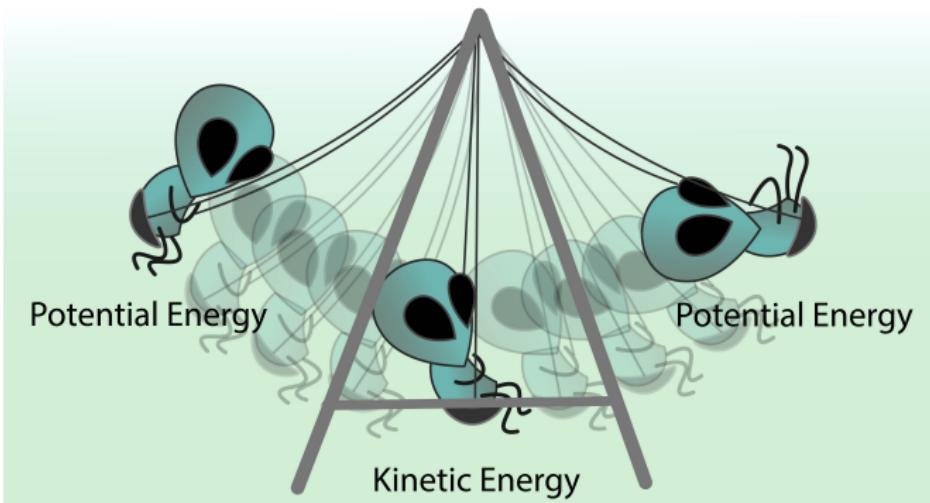


# Introduction to Electrical Circuits





# Energy



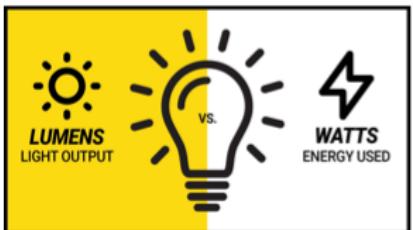
- Kinetic Energy - energy of motion
- Potential Energy - energy stored in an object



# Electrical Circuit Terms

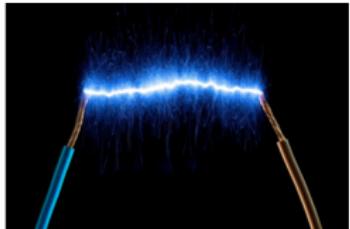


Voltage is **electric potential energy per unit charge** ( $V = J/C$ )

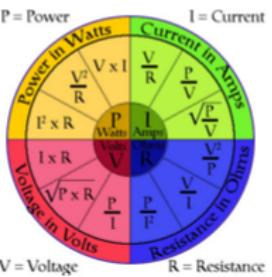


Power is the rate of doing work or **the rate of using energy**. ( $W = J/S$ )

| The Sub-atomic Particles |          |                        |                          |
|--------------------------|----------|------------------------|--------------------------|
| Relative size            | Name     | Mass (Kg)              | Charge (C)               |
| Proton                   | Proton   | $1.67 \times 10^{-27}$ | $+1.602 \times 10^{-19}$ |
| Neutron                  | Neutron  | $1.67 \times 10^{-27}$ | 0                        |
| Electron                 | Electron | $9.11 \times 10^{-31}$ | $-1.602 \times 10^{-19}$ |



Electric current is the **rate of charge flow** ( $A = C/s$ )



$$\text{Power} = \text{Voltage} \times \text{Current}$$



Energy is the **amount of power produced or consumed over a given time**. ( $J = W \times s$ )

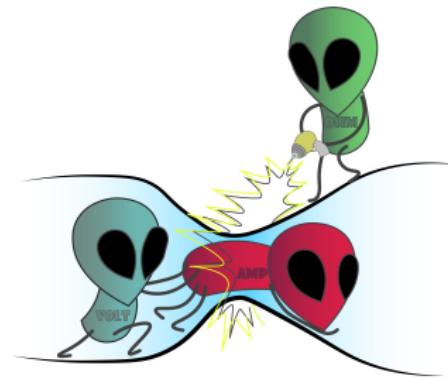
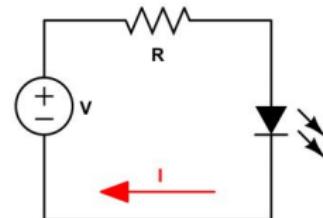


# Ohm's Law

Georg Ohm (16 March 1789 – 6 July 1854) was a German physicist and mathematician. As a school teacher, Ohm began his research with the new electrochemical cell, invented by Italian scientist Alessandro Volta. Ohm found that there is a direct proportionality between the potential difference (voltage) applied across a conductor and the resultant electric current. This relationship is known as Ohm's law:

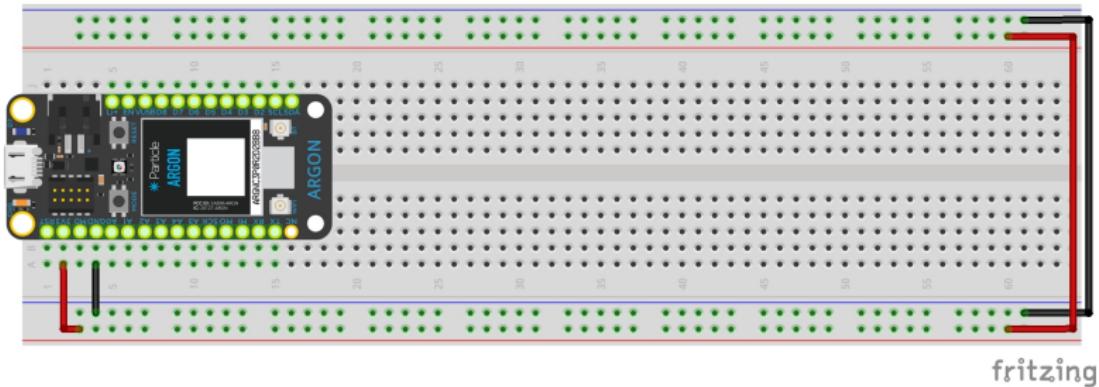
## Ohm's Law

$$V = I * R$$





# Power from the Argon



The Particle Argon has three pins related to power:

- 3.3V: 500mA of power to be used for most hardware
- $V_{BUS}$ : 5V from the USB cable to power 5V hardware
- GND: The ground pin to close the electrical loop

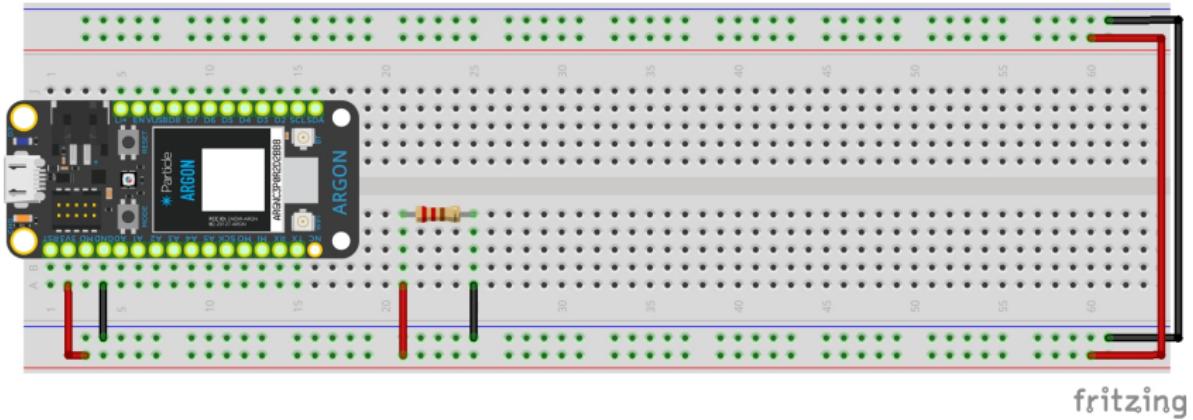


# Measuring Voltage, Current, and Resistance





# One Resistor



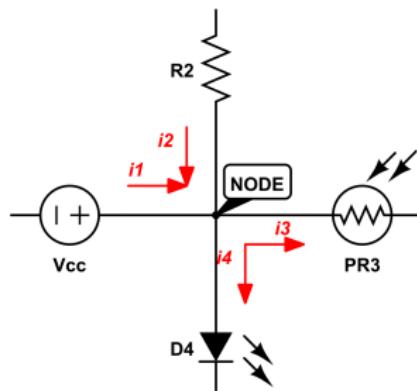
Using your multimeter, measure the voltage "across" and current "through" the resistor.



# Kirchhoff's First Law

Gustav Robert Kirchhoff (12 March 1824 – 17 October 1887) was a German physicist who contributed to the fundamental understanding of electrical circuits. His first law:

In an electrical circuit, the sum of currents flowing into that node is equal to the sum of currents flowing out of that node

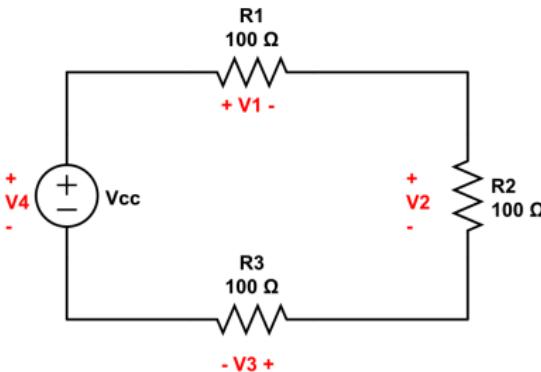


$$i_1 + i_2 = i_3 + i_4$$



# Kirchhoff's Second Law

The directed sum of the potential differences (voltages) around any closed loop is zero.



$$V4 - (V1 + V2 + V3) = 0$$

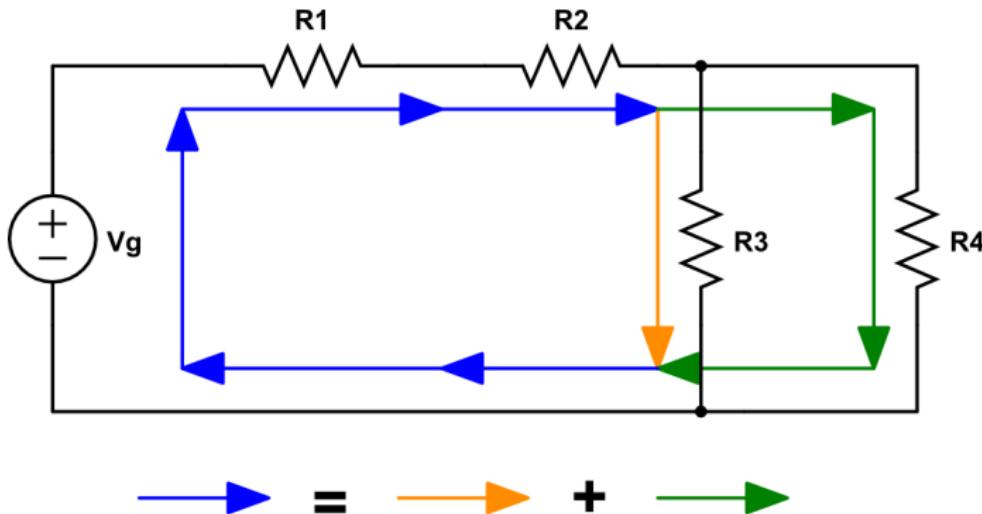


# Kirchhoff's Second Law



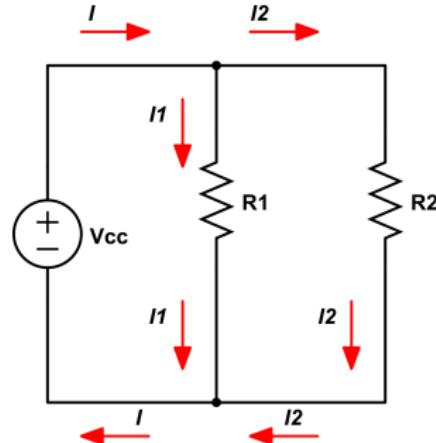
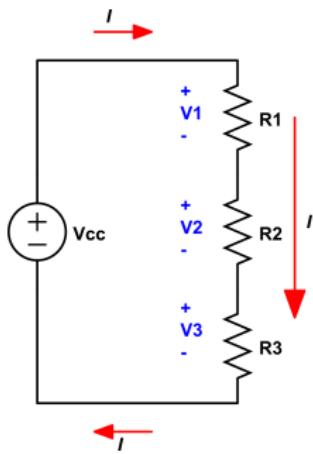


# Resistors in Series and Parallel





# Resistors in Series and Parallel

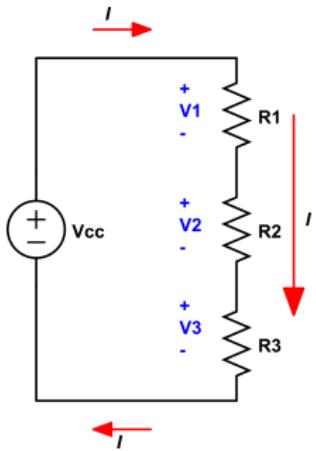


$$R_{eq} = R_1 + R_2 + R_3$$

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$$



# Resistors in Series



$$V_{cc} = V_1 + V_2 + V_3 \quad (1)$$

$$V_{cc} = IR_1 + IR_2 + IR_3 \quad (2)$$

$$V_{cc} = I(R_1 + R_2 + R_3) \quad (3)$$

Node Law:  $I = I_1 = I_2 = I_3$

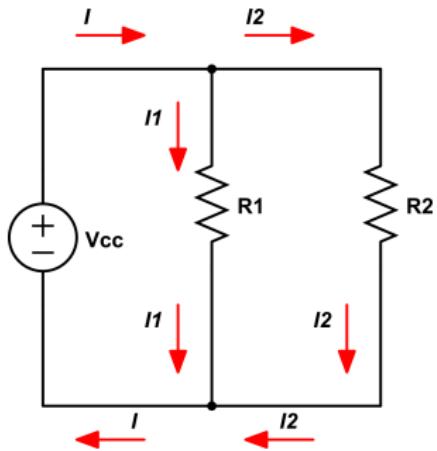
Loop Law:

$$V_{cc} - (V_1 + V_2 + V_3) = 0$$

$$R_{eq} = R_1 + R_2 + R_3 \quad (4)$$



# Resistors in Parallel



$$I = I_1 + I_2 \quad (5)$$

$$I = \frac{V_1}{R_1} + \frac{V_2}{R_2} \quad (6)$$

$$I = \frac{V_{cc}}{R_1} + \frac{V_{cc}}{R_2} \quad (7)$$

$$\frac{V_{cc}}{R_{eq}} = V_{cc} \left( \frac{1}{R_1} + \frac{1}{R_2} \right) \quad (8)$$

Node Law:  $I = I_1 + I_2$

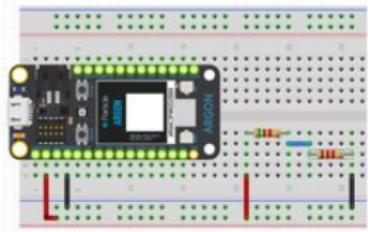
Loop Law:  $V_{cc} = V_1 = V_2$

$$\frac{1}{R_{eq}} = \left( \frac{1}{R_1} + \frac{1}{R_2} \right) \quad (9)$$

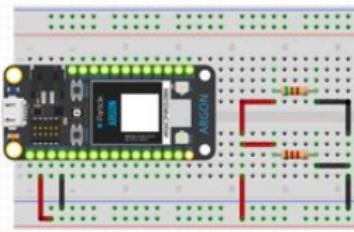


# Assignment: L02\_00\_Resistors

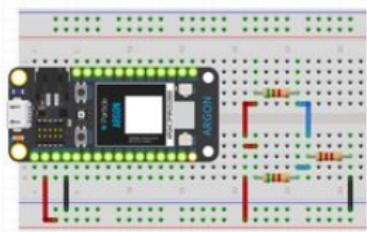
Series



Parallel



Combined

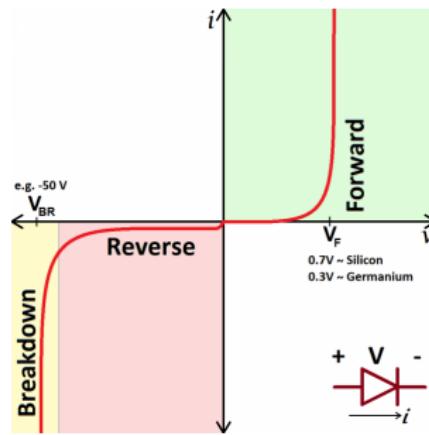


- In your lab notebook, draw the circuit diagrams
  - ① Series:  $5.1\text{k}\Omega$  and  $1.2\text{k}\Omega$
  - ② Parallel:  $5.1\text{k}\Omega$  and  $1.2\text{k}\Omega$
  - ③ Combined: Two parallel  $5.1\text{k}\Omega$  in series with  $1.2\text{k}\Omega$
- Calculate the combined resistance, the voltage at each node, and the current through each component.
- Create Fritzing diagram.
- Build (**one at a time**) on your breadboard and test your calculations with a multimeter.



# Diodes

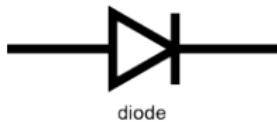
The key function of a diode is to control the direction of current-flow. Current passing through a diode can only go in one direction, called the forward direction. Current trying to flow the reverse direction is blocked.





# Light Emitting Diodes

LEDs (that's "ell-ee-dees") are a particular type of diode that convert electrical energy into light.



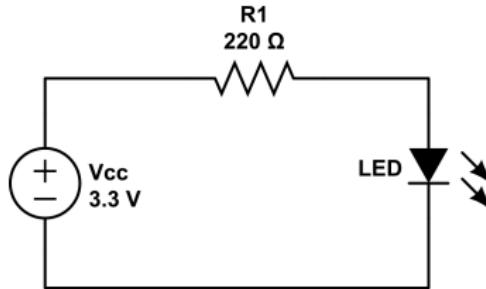


# Current Limiting Resistors

As an LED has very little resistance, when it is connected directly to a power supply, the current draw will exceed its specifications and it will burn out.

$$V_{cc} - V_{LED} = IR \implies R >= \frac{V_{cc} - V_{LED}}{I_{max}}$$

For a 3.3V power supply, a 0.43V across the LED, and a max current of 100mA, the resistor needs to be greater than  $29\Omega$ .





# SYSTEM\_MODE

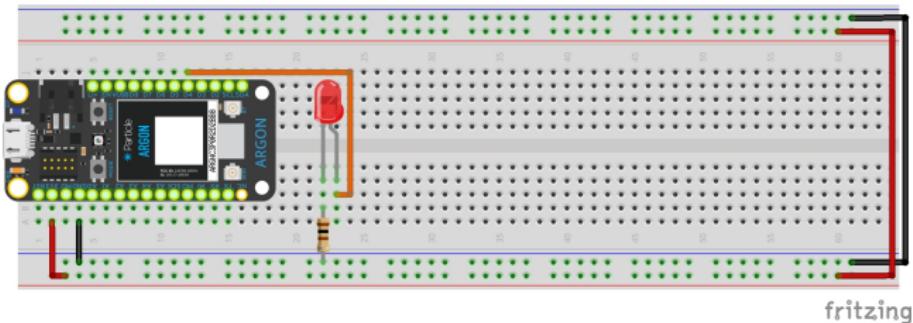
System modes help control how the device manages the connection with the cloud. By default, the device connects to the Cloud and processes messages automatically. However there are many cases where a user will want to take control over that connection. There are three available system modes:

- AUTOMATIC,
- SEMI\_AUTOMATIC,
- MANUAL.

```
1 //The below is placed in the header before Void Setup()
2
3 // SYSTEM_MODE(AUTOMATIC);           // Default if no SYSTEM_MODE included
4 // SYSTEM_MODE(SEMI_AUTOMATIC);     // Uncomment if using without Wifi
5 // SYSTEM_MODE(MANUAL);            // Fully Manual
```



# Assignment L02\_01\_helloLED



fritzing

- Using Pin D4 as an output and the appropriate current limiting resistor, blink the LED once per second.
- Measure the voltage at both leads of the LED and record the voltage in your notebook.
- Change the resistor to  $1k\Omega$  and then  $10k\Omega$ . What happens to the brightness? Measure the voltage and current in each case. Record in your notebook.

**REMEMBER:** Lab notebook, Fritzing, breadboard, then code



# Constants and Variables

It is often useful to give a name to something that will be used repeatedly in the code. Such items can be constants or variables:

- A **Constant** is a declaration that does not change throughout the code. For example, the pin that an LED is attached to.
- A **Variable** is a declaration that changes as the code processes. For example, a counter or index.

The use of Constants and Variables has several advantages:

- It improves readability by assigning names to items.
- Items can be changed by editing a single declaration.
- It allows the code to do math.

The first two Data Types that we will be using:

- **int**: an Integer between  $\pm 2,147,483,648$ .
- **float**: a Floating point number with 7-digits precision.



## IoT Style Guide - camelCase



Camel Case is the practice of writing phrases without spaces or punctuation, indicating the separation of words with a single capitalized letter, and the first word starting with either case. In IoT, we will start the first word as lowercase and subsequent words with upper case to delineate words.



# Operators

There are a number of operators that act on variables:

```
1 // Assignment
2 x = y;      // assign x to be equal to y
3
4 // Math Operators
5 sum = x + y;
6 difference = x - y;
7 product = x * y;
8 quotient = x / y;
9 remainder = x % y;
10
11 // Incrementing
12 i = i + 1;
13 i += 1;
14 i++;
15
16 // Decrementing
17 i = i - 1;
18 i -= 1;
19 i--;
20
21 // Comparison
22 (x == y); // true if x is equal to y
23 (x != y); // true if x is not equal to y
24 (x > y); // true if x is greater than y
25 (x >= y); // true if x is greater than or equal to y
26 (x < y); // true if x is less than y
27 (x <= y); // true if x is less than or equal to y
```

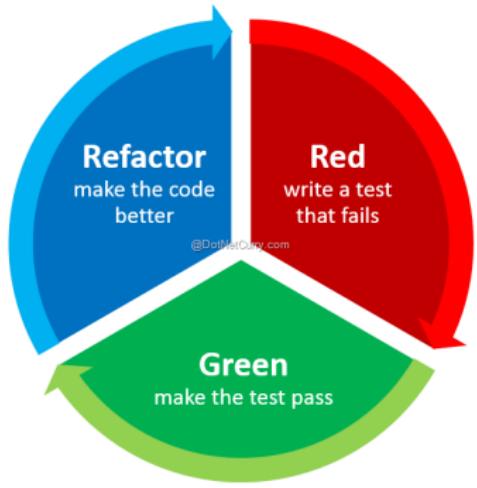


## Constants and Variables Example

```
1 const int LEDPIN = 5;
2 const int LEDDELAY = 1000;
3 int i;
4
5 void setup() {
6     pinMode(LEDPIN, OUTPUT); //set LEDPIN as Output
7     i = 100;
8 }
9 void loop() {
10    digitalWrite(LEDPIN, HIGH);
11    delay(LEDDelay);
12    digitalWrite(LEDPIN, LOW);
13    delay(LEDDelay+i);
14    i = i + 100;
15 }
```



## Assignment L02\_02\_helloLEDvar



- Refactor your L02\_01\_helloLED code to use constants and/or variables.

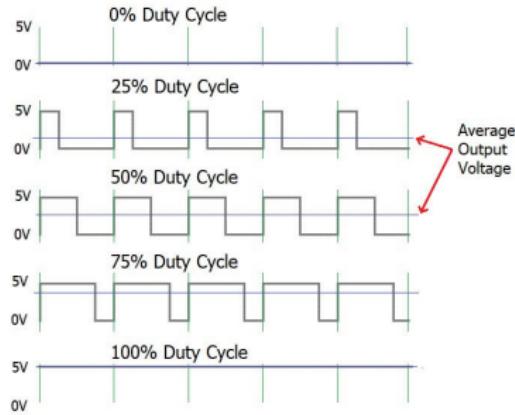
*Note: refactoring code is when you rewrite portions of your code to make it more readable, or to make it run more efficiently.*



# Pulse Width Modulation

## Software Configurable:

- Digital Input: High/Low (3.3V/0V)
- Digital Output: High/Low (3.3V/0V)
- Analog Input: 0V to 3.3V
- Analog Output: 0V to 3.3V PWM





# Assignment L02\_03\_helloLEDDigital



Use `analogWrite` to change the brightness of the LED, using values:

- 255
- 63
- 171
- 16

Measure the voltage with your multimeter at each value.

Syntax: `analogWrite(pin,value);`

- pin: the pin to write to
- value: the duty cycle of the pulses, an int between 0 (always off) and 255 (always on)

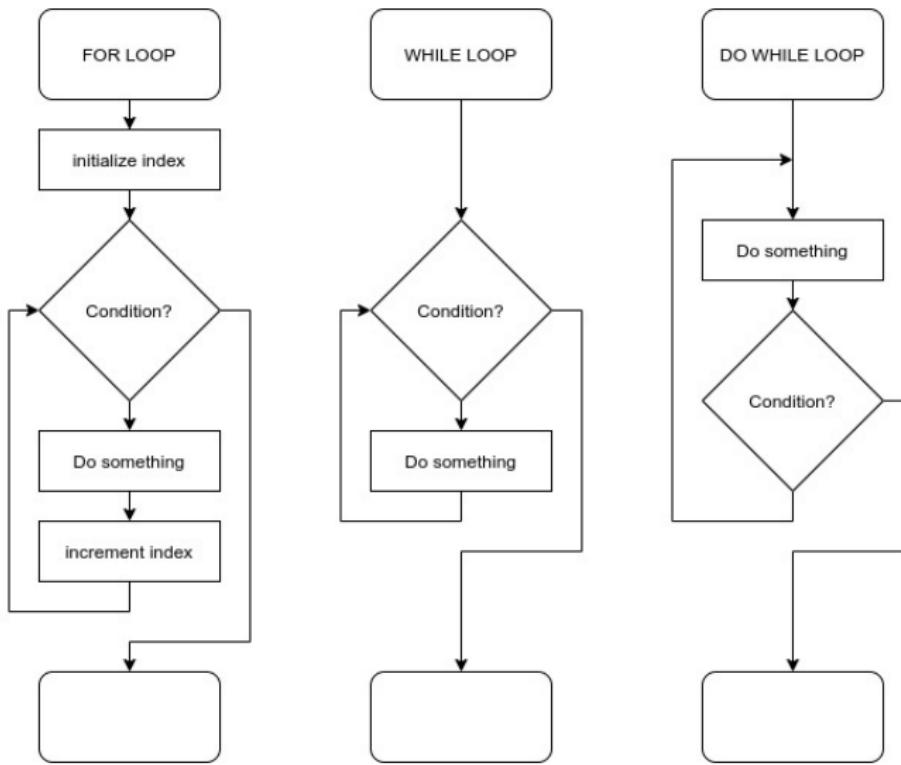


# Flowcharts

| Symbol | Name               | Function   |
|--------|--------------------|--|
|        | Process            | Indicates any type of internal operation inside the Processor or Memory                                      |
|        | input/output       | Used for any Input / Output (I/O) operation. Indicates that the computer is to obtain data or output results |
|        | Decision           | Used to ask a question that can be answered in a binary format (Yes/No, True/False)                          |
|        | Connector          | Allows the flowchart to be drawn without intersecting lines or without a reverse flow.                       |
|        | Predefined Process | Used to invoke a subroutine or an Interrupt program.   |
|        | Terminal           | Indicates the starting or ending of the program, process, or interrupt program                               |
|        | Flow Lines         | Shows direction of flow.   |



# Loops





# FOR Loop syntax

```
1 // FOR loop syntax
2 for (initialization; condition; increment) {
3     // statement(s);
4 }
5
6 // EXAMPLE
7 for (j=0; j <= 255; j++) {
8     analogWrite(LEDPIN, j);
9 }
```

*Note: the third parameter of a FOR loop can also decrement; i.e.  $j--$  or can go up or down by a specified amount; i.e.  $j = j + 2$*



# WHILE loop syntax

```
1 // WHILE loop syntax
2 while (condition) {
3     // statement(s)
4 }
5
6
7 // EXAMPLE
8 while (button == HIGH) {
9     digitalWrite(LEDPIN, HIGH);
10 } //continue this loop until button is released
```



# For vs While Loops

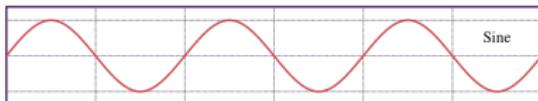
## For VS While Loop

Comparison Chart

| For Loop  | While Loop   |
|---|--|
| The for loop is used for definite loops when the number of iterations is known.   | The while loop is used when the number of iterations is not known.                       |
| For loops can have their counter variables declared in the declaration itself.    | There is no built-in loop control variable with a while loop.                            |
| This is preferable when we know exactly how many times the loop will be repeated. | The while loop will continue to run infinite number of times until the condition is met. |
| The loop iterates infinite number of times if the condition is not specified.     | If the condition is not specified, it shows a compilation error.                         |



# Assignment L02\_04\_helloLEDtri



Using a FOR Loop, have the LEDs follow a Triangle Wave function from off to full brightness with a period of 10 seconds.

Before you write code, create a flow chart of the logic to create a triangle wave.



# While or Do While





# Number Systems

Decimal

92<sub>10</sub>

Digits: 0,1,2,3,4,5,6,7,8,9

Binary

01011100<sub>2</sub>

Digits: 0,1

Hexadecimal

5C<sub>16</sub>

Digits: 0,1,2,3,4,5,6,7,8,9,A,B,C,D,E,F

Octal

134<sub>8</sub>

Digits: 0,1,2,3,4,5,6,7



# Exponents

## Whole Number Exponents

whole # exponent  $\rightarrow$

$$x^a = \underbrace{x \cdot x \cdot x \cdot \dots \cdot x}_{a \text{ times}}$$

base

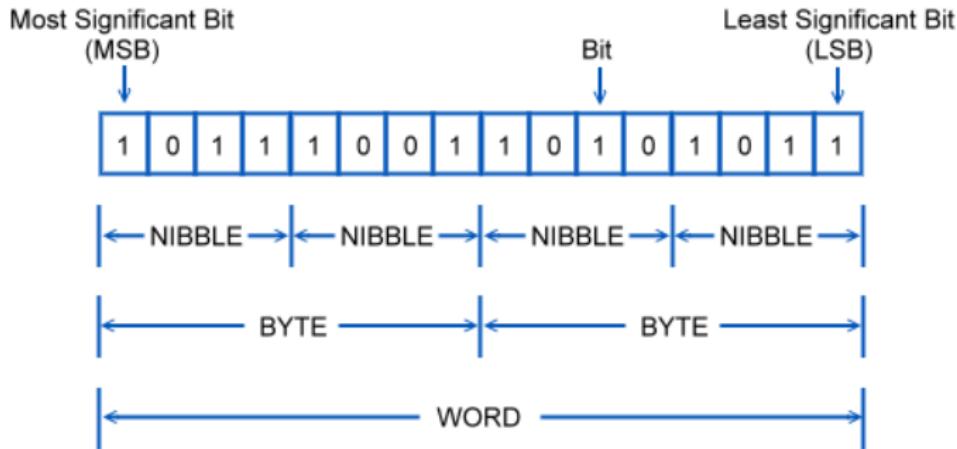
Example:  $2^3 = 2 \cdot 2 \cdot 2 = 8$

The rule for zero as an exponent:

Any nonzero real number raised to the power of zero is one, this means anything that looks like  $x^0$  will always equal 1 if  $x$  is not equal to zero.



# Bits, Nibbles, Bytes, and Words





# Data Types: Numbers

| Data Type   | 8-bit AVR systems (Arduino Uno) |                               |                                 | 32-bit ARM systems (Teensy 3.2) |                               |                                 |
|-------------|---------------------------------|-------------------------------|---------------------------------|---------------------------------|-------------------------------|---------------------------------|
|             | bytes                           | range (signed)                | range (unsigned)                | bytes                           | range (signed)                | range (unsigned)                |
| char        | 1                               | -128 to 127                   | 0 to 255                        | 1                               | -128 to 127                   | 0 to 255                        |
| short       | 2                               | +/- 32,767                    | 0 to 65,353                     | 2                               | +/- 32,767                    | 0 to 65,353                     |
| int         | 2                               | +/- 32,767                    | 0 to 65,353                     | 4                               | +/- 2,147,483,648             | 0 - 4,294,967,295               |
| long        | 4                               | +/- 2,147,483,648             | 0 - 4,294,967,295               | 4                               | +/- 2,147,483,648             | 0 - 4,294,967,295               |
| long long   | 8                               | +/- 9,223,372,036,854,770,000 | 0 to 18,446,744,073,709,551,615 | 8                               | +/- 9,223,372,036,854,770,000 | 0 to 18,446,744,073,709,551,615 |
| float       | 4                               | 3.4E +/- 38 (7 digits)        | n/a                             | 4                               | 3.4E +/- 38 (7 digits)        | n/a                             |
| double      | 4                               | 3.4E +/- 38 (7 digits)        | n/a                             | 8                               | 1.7E +/- 308 (15 digits)      | n/a                             |
| long double | 8                               | 1.7E +/- 308 (15 digits)      | n/a                             | 8                               | 1.7E +/- 308 (15 digits)      | n/a                             |
| Unambiguous |                                 |                               |                                 |                                 |                               |                                 |
| uint8_t     | 1                               | n/a                           | 0 to 255                        | 1                               | n/a                           | 0 to 255                        |
| int8_t      | 1                               | -128 to 127                   | n/a                             | 1                               | -128 to 127                   | n/a                             |
| uint16_t    | 2                               | n/a                           | 0 to 65,353                     | 2                               | n/a                           | 0 to 65,353                     |
| int16_t     | 2                               | +/- 32,767                    | n/a                             | 2                               | +/- 32,767                    | n/a                             |
| uint32_t    | 4                               | n/a                           | 0 - 4,294,967,295               | 4                               | n/a                           | 0 - 4,294,967,295               |
| int32_t     | 4                               | +/- 2,147,483,648             | n/a                             | 4                               | +/- 2,147,483,648             | n/a                             |

There are  $7.5 \times 10^{18}$  grains of sand on Earth. A long long integer and the floating point numbers are larger than this.

MATH NOTE: An Integer divided by an Integer always returns an Integer



# Math Warning and Type Casting

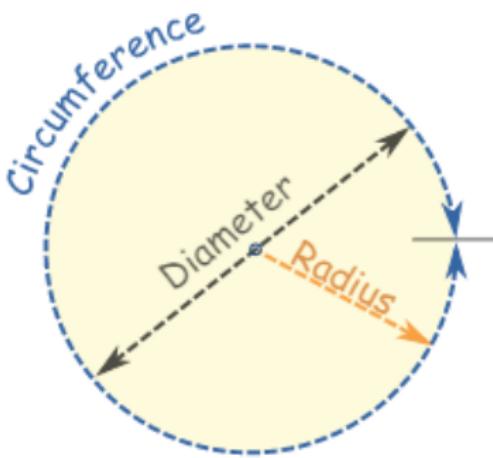
Be cognizant of the data type when performing math operations.

```
1 int x = 3;
2 int y = 2;
3 float yf = 2.0;
4 float z;
5
6 //int divided by an int returns an int
7 z = x/y;                      // z = 1.0
8 z = x/yf;                     // z = 1.5
9 z = x / 2;                     // z = 1.0
10 z = x / 2.0;                  // z = 1.5
11
12 //type casting used to change datatype
13 z = (float) x / (float) y;    // z = 1.5
14 z = x / (float) y;           // z = 1.5
15
16 z = (int) (x / yf);         // z = 1.0
17 y = x / yf;                 // y = 1
```

Type Casting is a way to ensure that you are correctly moving between datatypes



# Pi ( $\pi$ )

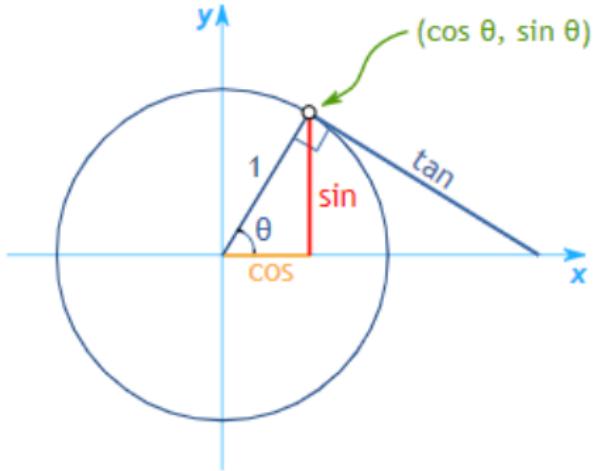
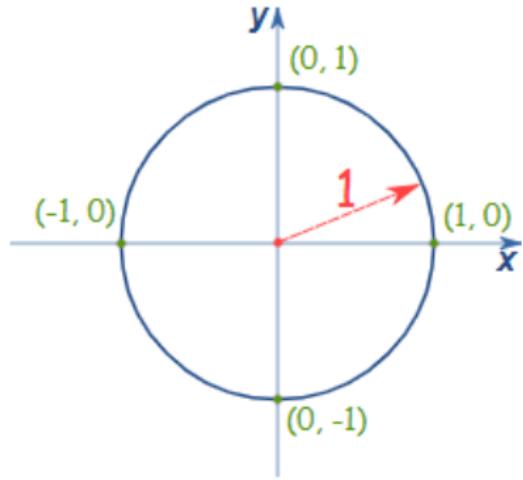


$$\frac{\text{Circumference}}{\text{Diameter}} = \pi = 3.14159\dots$$



# Unit Circle and Trigonometric Functions

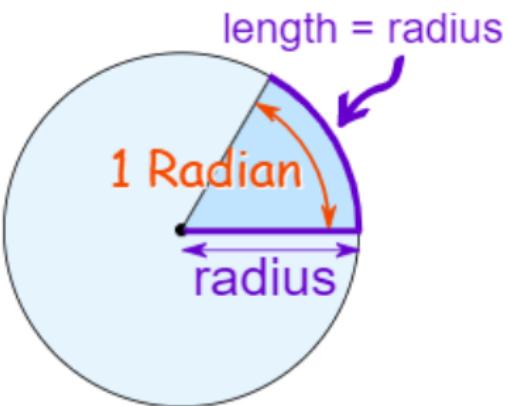
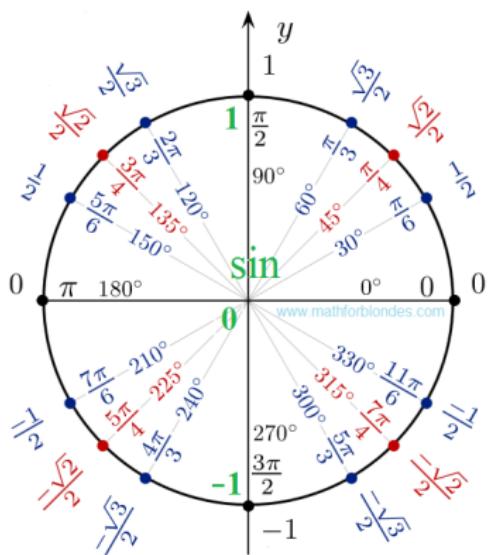
The Unit Circle is a circle with a radius of 1.



The Unit Circle can be used to map out the trigonometric values of sine, cosine, and tangent.



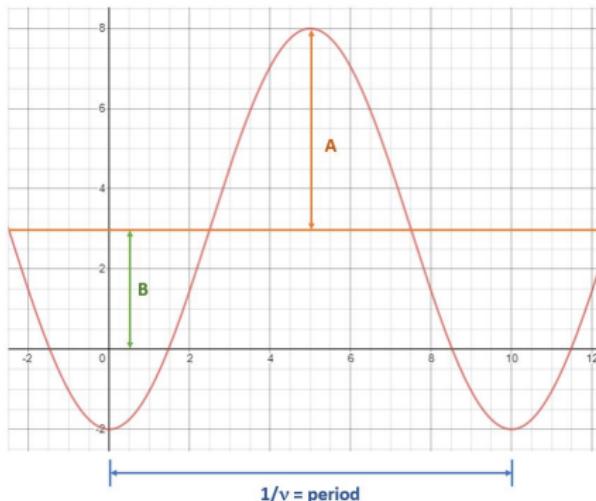
# Unit Circle and the Value of $\sin(\theta)$



- $\sin(\theta)$  is the y-value of the point on the Unit Circle at angle  $\theta$ .
- In our trig functions,  $\theta$  is measured in radians (rad), not degrees.
- $360$  degrees =  $2\pi$  radians.



# Sine Waves

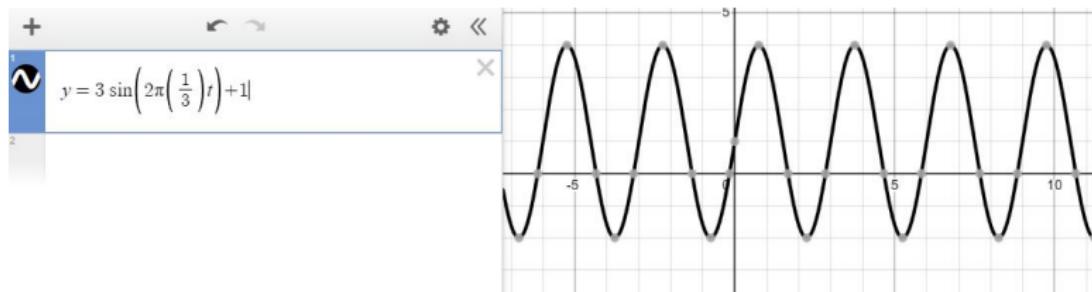
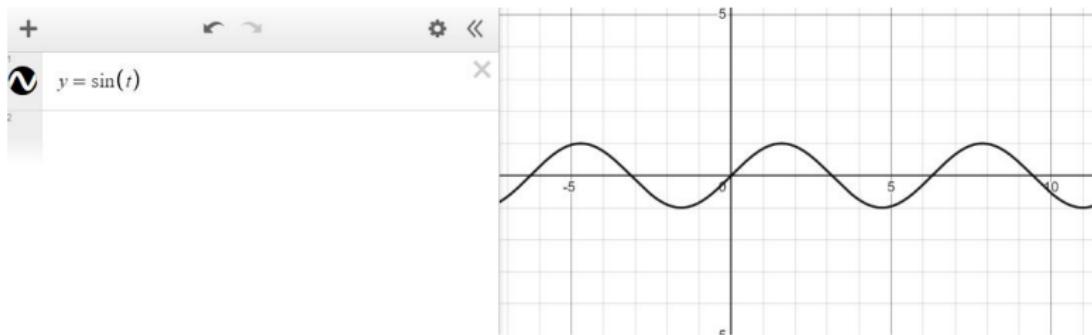


$$y = A * \sin(2 * \pi * \nu * t) + B$$

where  $A$  = amplitude,  $B$  = offset,  $\nu$  = frequency =  $\frac{1}{\text{period}}$ ,  
and  $t$  = time in seconds.



# Using Desmos (desmos.com/calculator)





## Header Files

A header file is a file with the extension .h which contains C function declarations and macro definitions to be shared between several source files. There are two types of header files; those that the programmer writes and those that come with the compiler.

Both the user and system header files are included using the preprocessing directive #include. It has the following two forms:

- `#include <file.h>` for system header files.
- `#include "file.h"` for user-created header files in the directory that contains the current code.

An example of a system header file is the math.h header that defines various mathematical functions.

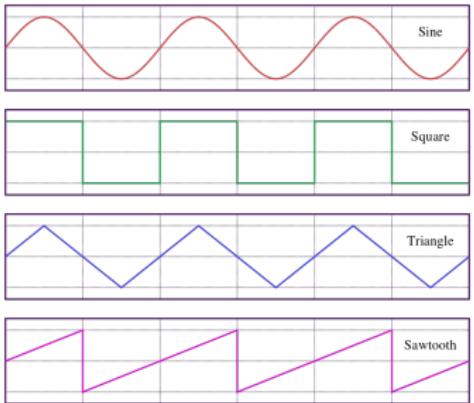


## Basic Structure of Arduino Sketch Revisited

```
1 #include <math.h>          // include header files
2 const int LEDPIN = 5;      // declare constants
3 float value,n;            // declare variables
4
5 void setup() {             // runs once
6   pinMode(LEDPIN,OUTPUT);  // system settings
7   n = 0;                  // set variables
8 }
9
10 void loop() {              // loops indefinitely
11   value = sin(2*M_PI*n);
12   n = n+0.25;             // move a quarter around
13                           // the unit circle
14 }
```



## Assignment L02\_05\_helloLEDsin



Use a `sin()` function to vary the brightness of your LED.

- Use `math.h`.
- Function `sin()` takes a double as an input and returns a double.
- Set the period to 5 seconds.

Recall: for a sin wave:  $y = A * \sin(2 * \pi * \nu * t) + B$

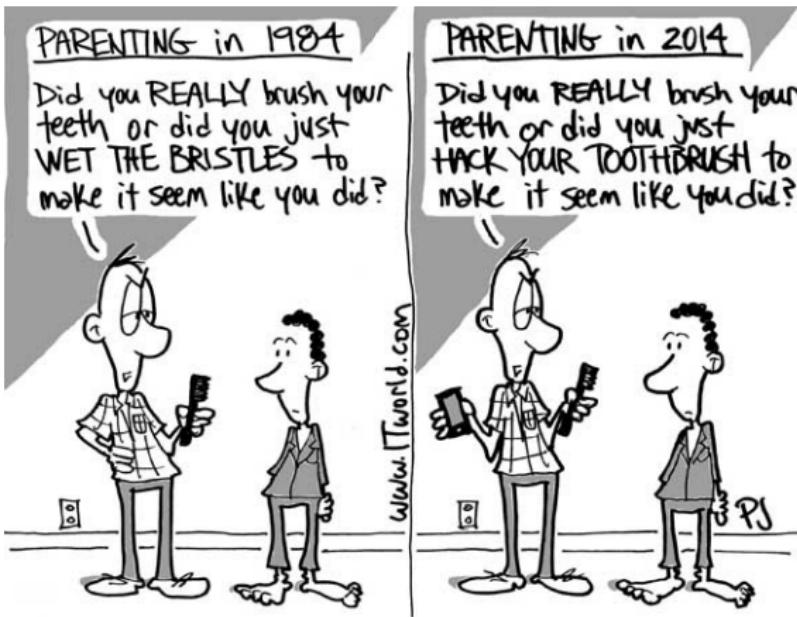
The function `millis()` returns milliseconds since the Argon has been powered on. For the sine equation, use  $t = \text{millis()} / 1000.0$ .

Why is adding the decimal after 1000 important?

# Module 3 - Buttons



# IoT Fun





# Displaying to the Screen: The Serial Monitor

```
1 void setup() {  
2  
3     // Enable Serial Monitor  
4     Serial.begin (9600);  
5     waitFor(Serial.isConnected,10000); // wait for  
6     Serial monitor  
7     Serial.println ("Ready to Go");  
8 }  
9  
10 void loop() {  
11     for (i=0; i<=13; i++){  
12         Serial.print(i);  
13         delay(printDelay);  
14     }  
15 }
```



# Print Statements

- ① Serial.print() prints data to the monitor through the serial port as human-readable text:
  - Serial.print('N') prints: N (works for single character only)
  - Serial.print("Hello World") prints: Hello World
  - Serial.print(78) prints: 78
  - Serial.print(3.141592) prints 3.14
  - Serial.print(3.141592,5) prints 3.14159
- ② Serial.println() displays the print() followed by a carriage return (\r) or newline (\n).
- ③ Serial.printf() displays a formatted print.



# Format Specifiers Statements

`printf("a = %d\nb = %d\n", a, b);`

| specifier | Output  | Example       |
|-----------|---|---------------|
| d or i    | Signed decimal integer  | 392           |
| u         | Unsigned decimal integer  | 7235          |
| o         | Unsigned octal  | 610           |
| x         | Unsigned hexadecimal integer  | 7F8           |
| X         | Unsigned hexadecimal integer (uppercase)  | 7FA           |
| f         | Decimal floating point, lowercase   | 392.65        |
| F         | Decimal floating point, uppercase   | 392.65        |
| e         | Scientific notation (mantissa/exponent), lowercase  | 3.9265e+2     |
| E         | Scientific notation (mantissa/exponent), uppercase  | 3.9265E+2     |
| g         | Use the shortest representation: %e or %f   | 392.65        |
| G         | Use the shortest representation: %E or %F   | 392.65        |
| a         | Hexadecimal floating point, lowercase   | -0xc.90feP-2  |
| A         | Hexadecimal floating point, uppercase   | -0XC.90FEPE-2 |
| c         | Character   | a             |
| s         | String of characters  | sample        |
| p         | Pointer address   | b8000000      |
| n         | Nothing printed.<br>The corresponding argument must be a pointer to a signed int.<br>The number of characters written so far is stored in the pointed location. |               |
| %         | A % followed by another % character will write a single % to the stream.  | %             |

```

1 int count = 42;
2 float value = 3.14159;
3 Serial.printf("Print an integer %i and a float %0.4f\n",count,value);
4
5 //Output: Print an integer 42 and a float 3.1415

```



# Opening the Serial Monitor

Access the Command Palette - Ctrl-Shift-P

The screenshot shows the Particle IDE's Command Palette open. The search bar at the top contains the text '>particle'. Below the search bar is a list of recently used commands, each preceded by a blue 'Particle' icon. The commands listed are: 'Install Library', 'Find Libraries', 'Cloud Compile', 'Configure Workspace for Device', 'Launch CLI', 'Install Local Compiler', 'Cloud Flash', 'Serial Monitor', 'Create New Project', 'Audit Environment', 'Who Am I?', 'Clean application (local)', and 'Clean application & DeviceOS (local)'. A 'recently used' label is positioned to the right of the first few items, and an 'other commands' label is positioned to the right of the last item.

| recently used                                  |
|--|
| >particle                                      |
| Particle: Install Library                      |
| Particle: Find Libraries                       |
| Particle: Cloud Compile                        |
| Particle: Configure Workspace for Device       |
| Particle: Launch CLI                           |
| Particle: Install Local Compiler               |
| Particle: Cloud Flash                          |
| Particle: Serial Monitor                       |
| Particle: Create New Project                   |
| Particle: Audit Environment                    |
| Particle: Who Am I?                            |
| Particle: Clean application (local)            |
| Particle: Clean application & DeviceOS (local) |

other commands

Or, open the Serial Monitor in Powershell or Terminal:

```
1 particle serial monitor --follow
```



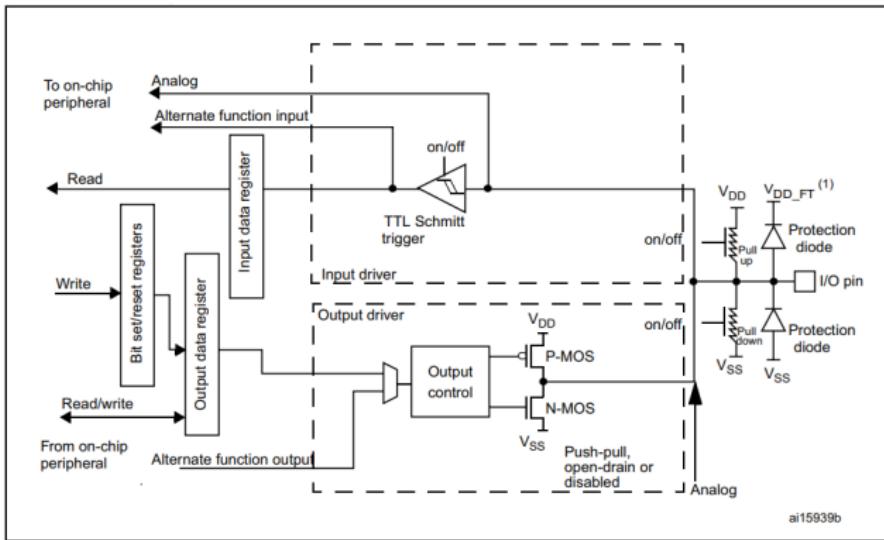
# Assignment L03\_00\_SerialMonitor



- ① Print Hello World to your monitor screen.
- ② Next, display to the screen a count from 0 to 13, separated by commas, three times by using:
  - Serial.print();
  - Serial.println();
  - Serial.printf();



# One Pin - Many Functions

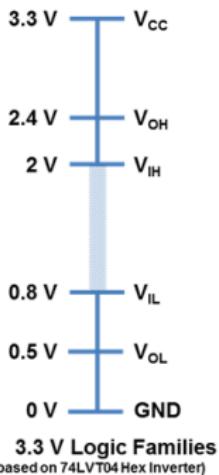


Software Programmable: Input or Output and Digital or Analog.



# Digital Input/Output

Digital electronics rely on binary logic to store, process, and transmit data or information. Binary Logic refers to one of two states – ON or OFF. This is commonly translated as a binary 1 or binary 0. A binary 1 is also referred to as a HIGH signal and a binary 0 is referred to as a LOW signal.

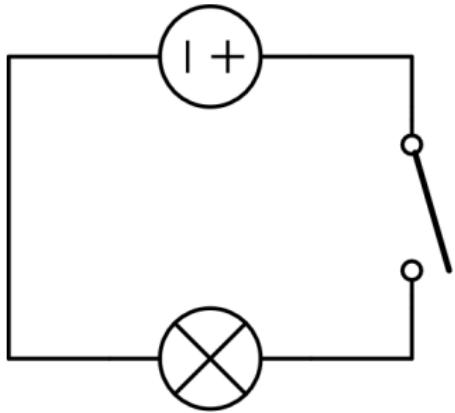


- `digitalWrite(pin,value);`
- `inputValue = digitalRead(pin);`

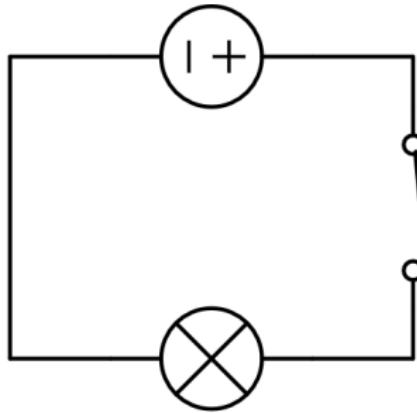
where, value equals HIGH or LOW.



# Switches



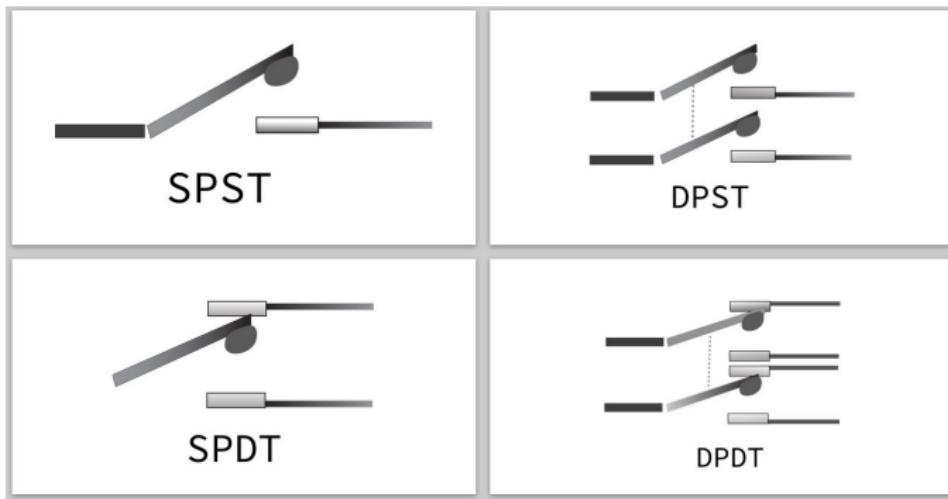
Lamp Off



Lamp On



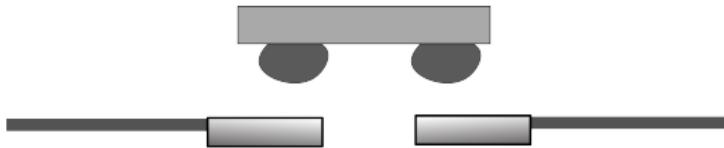
# Poles and Throws



- Poles indicates the number of circuits that one switch can control for one operation of the switch.
- Throws indicates the number of contact points.



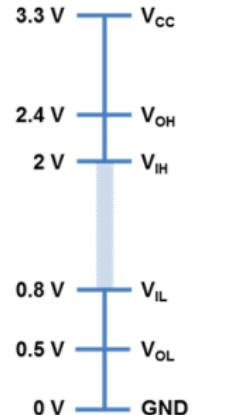
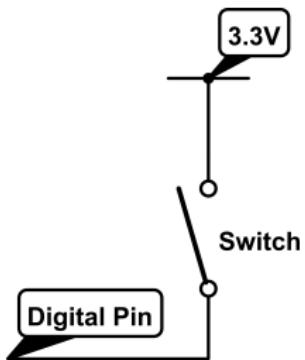
# A Button - SPST



**SPST**  
double break



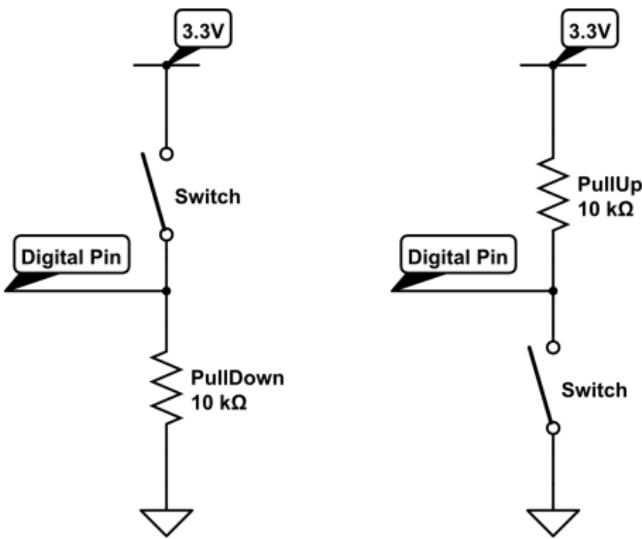
# Floating Inputs



3.3 V Logic Families  
(based on 74LVT04 Hex Inverter)



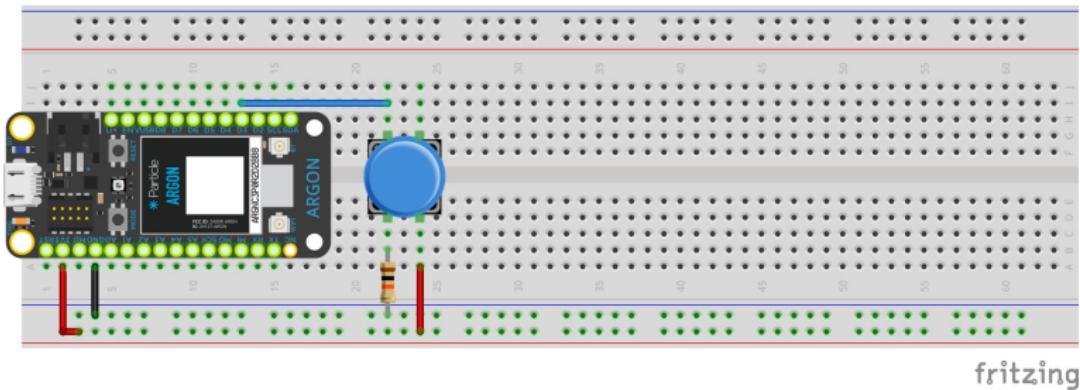
# Pull Down and Pull Up Resistors



- What happens if the digital pin is left floating when the switch is open?
- What happens if the pin is connected directly to GND (or  $V_{cc}$ ) without a resistor?



# Our First Button and Pull Down Resistors

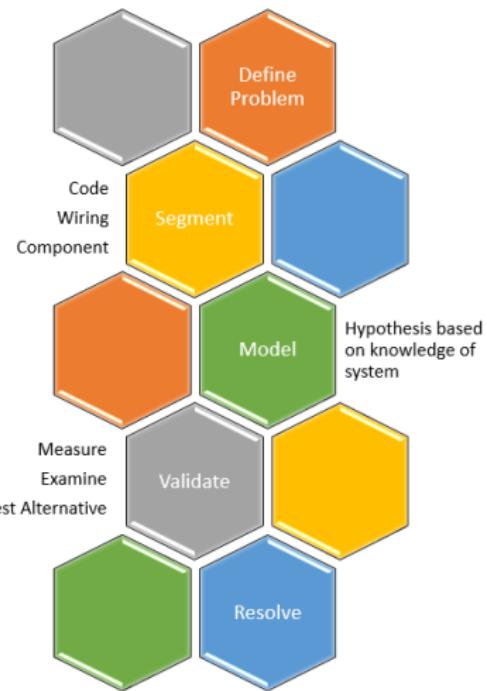


Reading from a digital pin:

- `inputValue = digitalRead(pin);`  
where
  - pin is the digital pin that the button is connected to
  - inputValue is an int (declared in the header)



# Model Based Troubleshooting





# Assignment: Buttons

Connect a button (and a multimeter to measure the voltage) to Pin D3.



- Notebook: draw circuit
- Fritzing diagram
- Wire your circuit
- Write the code

## ① L03\_01\_button

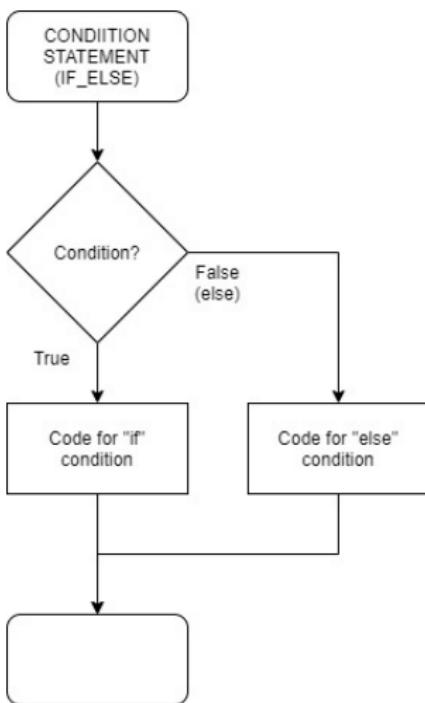
- Use `digitalRead()` to input the button state.
- Print button state to the screen.
- Remove the resistor. How does this affect the button state and the voltage?
- Replace the pull-down resistor with a pull-up. How does the logic change?
  - Not pressed: 3.3V
  - Pressed: GND

## ② L03\_02\_button\_input\_pullup

- Remove the pull-up resistor.
- Implement:  
`pinMode(pin,INPUT_PULLUP);`



# IF-ELSE Statements



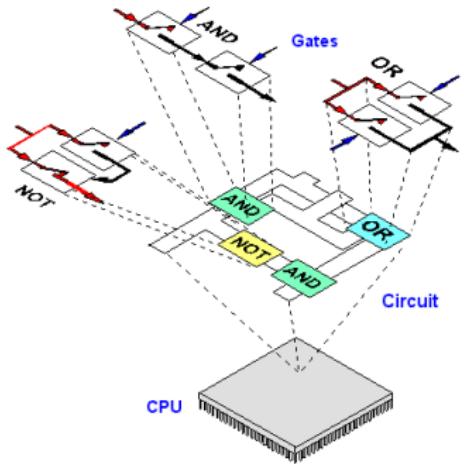


# IF-ELSE Statements

```
1 // IF statement SYNTAX
2 if (condition) {
3     //statement(s)
4 }
5 else {
6     // else statement(s)
7 }
8
9 // EXAMPLE
10 if (buttonState) {
11     Serial.printf("Button is pressed \n");
12 }
13 else {
14     Serial.printf("Button is not pressed \n");
15 }
```



# Data Types: Boolean and Boolean Logic



Boolean datatype (bool)  
holds either a TRUE or  
FALSE

Boolean Logic Operations (condition statements)

- ① NOT (!): true if operand is false and visa-versa
  - $x = !x$
- ② AND (&&): true if both operands are true
  - $z = x \&\& y$
- ③ OR (||): true if either operand is true
  - $z = x || y$

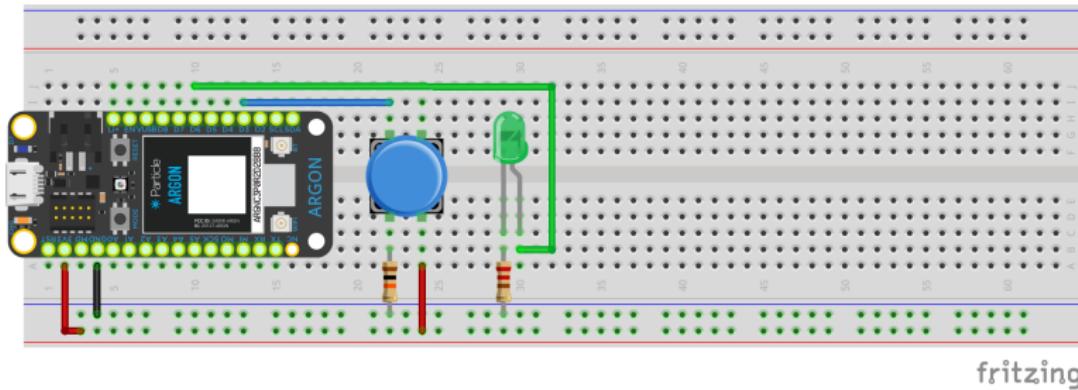


# Boolean Logic In Action

```
1 bool x;
2 bool buttonState1, buttonState2;
3 int y, z;
4
5 // ! (NOT) assignment function
6 x = !x;           // toggle x (if x = 1, then set x = 0, and visa-versa)
7
8 // ! (NOT) comparison
9 if (!x) {          // if x is false
10   // do something
11 }
12
13 // LOGICAL AND: if both pins are pressed
14 buttonState1 = digitalRead(PIN1);
15 buttonState2 = digitalRead(PIN2);
16 if ((buttonState1) && (buttonState2) {
17   // do something
18 }
19
20 // LOGICAL OR: if either value is greater than zero
21 if (y > 0 || z > 0) {
22   // do something
23 }
```



# Button and LED





# Assignment: Buttons and LEDs



Update your  
schematic and  
Fritzing

## ① L03\_03\_buttonLED

- Add a Green LED to Pin D6 and use D3 button to turn the LED on/off.
- Also, print button state to the screen

## ② L03\_04\_twoButtonLED

- Add a second button (Pin D2) and Yellow LED (Pin D5).
- Have each button control one LED.
- Also, print button states to the screen.

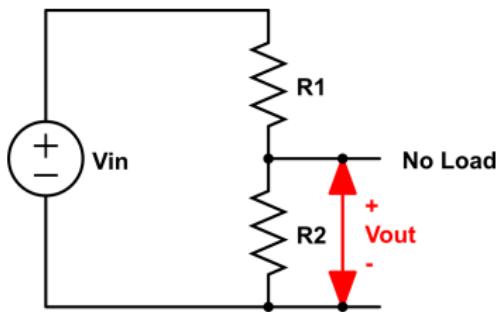
## ③ Extra Credit: Modify twoButton

- The Green LED lights up if both buttons are pressed
- The Yellow LED lights up if either button is pressed

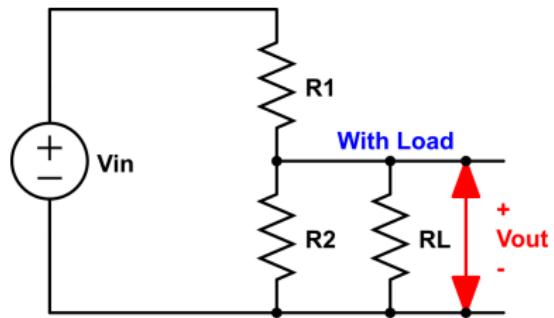


# Resistors in Series and Parallel

Open Circuit Behavior



Behavior Under Load

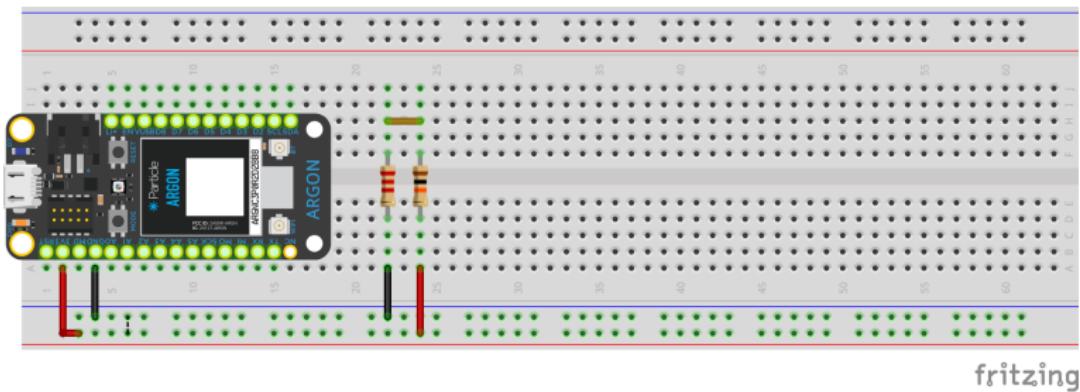


$$V_{out} = V_{in} \frac{IR_2}{I(R_1+R_2)} = \frac{R_2}{R_1+R_2} V_{in}$$

$$V_{out} = \frac{R_2 \parallel R_L}{R_1 + R_2 \parallel R_L} V_{in}$$



# Voltage Dividing

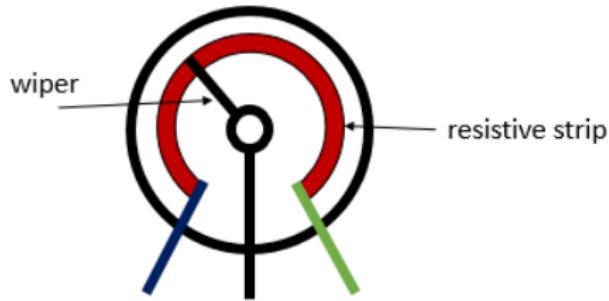


We are just using the Argon to provide Power and GND.

- Use various combinations of resistors between  $1k\Omega$  and  $22k\Omega$ .
- Calculate the Series resistance and the voltage between the two resistors in your Lab Notebook.
- Measure with your multimeter and compare.



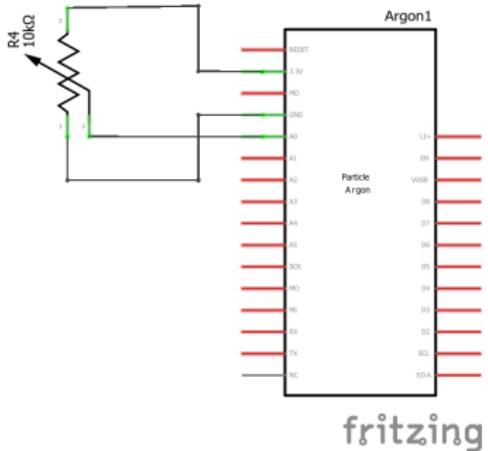
# Potentiometer - Variable Resistor



A potentiometer has 3 pins. Two terminals (the blue and green) are connected to a resistive element and the third terminal (the black one) is connected to an adjustable wiper.



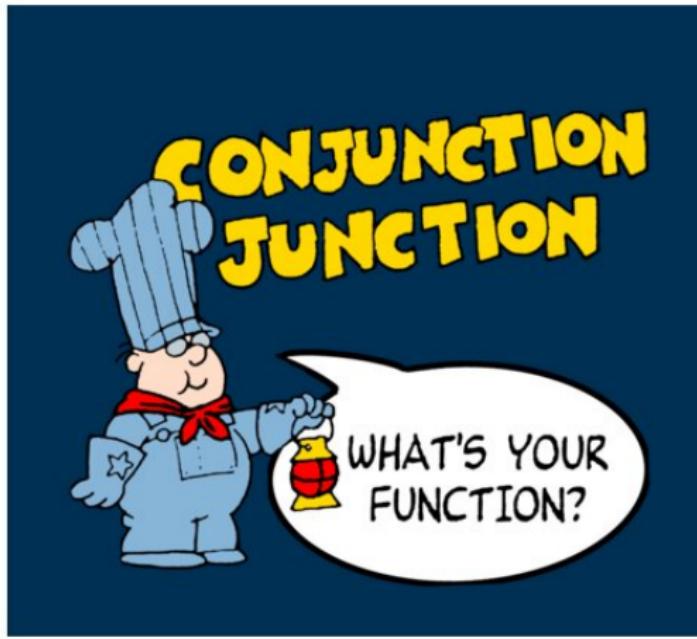
## Assignment L03\_05\_AnalogInput



- ① Look up the syntax of `analogRead()` in the Arduino Reference.
  - ② Utilize `analogRead()` to measure analog input across a potentiometer (voltage divider) using Pin A0.
  - ③ Determine the range of the `analogRead()` across the entire range of the potentiometer.



# Conjunction Junction





# Anatomy of a Function

## Anatomy of a C function

Datatype of data returned, any C datatype

"void" if nothing is returned

```
int myMultiplyFunction(int x, int y){  
    int result;  
    result = x * y;  
    return result;  
}
```

Function name

Parameters pass to function, any C datatype

Return statement, datatype matches declaration

Curly braces required



# Functions in Action

```
1 int variable1, variable2, answer;
2
3 // Declare (or prototype) the function in the header
4 int myMultiplyFunction(int x, int y);
5
6 void setup() {
7     Serial.begin(9600);
8 }
9
10 void loop() {
11     // Call the function
12     answer = myMultiplyFunction(variable1, variable2);
13     Serial.printf("%i times %i = %i\n", variable1, variable2, answer);
14     variable2 = answer;
15 }
16
17 // Define the function
18 int myMultiplyFunction(int x, int y) {
19     int result;
20
21     result = x * y;
22     return result;
23 }
```

The function needs to be: Declared, Defined, and Called (at least once)



# Types of Variables

```
1 int x;           // x is a global variable available in the entire program
2 int addx();      // declaration of function
3 void setup() {
4     x = 1;
5 }
6 void loop() {
7     x = addx();
8 }
9 int addx() {
10     int y = 0;      // y is a local variable, resets every function call
11     static int z = 0; // z is a static local variable, maintains its value
12     y = y + x;      // x is global, so value exists in function
13     z = z + x;
14     Serial.printf("x = %i, y = %i, and z = %i \n",x,y,z);
15     return z;
16 }
```

## ① Global Variables

- Accessible throughout the program and all functions.

## ② Local Variables

- Accessible only in the function.
- Created when function is called. Destroyed when function is returned.

## ③ Static Local Variables

- Accessible only in the function.
- Maintains value across multiple calls of a function.

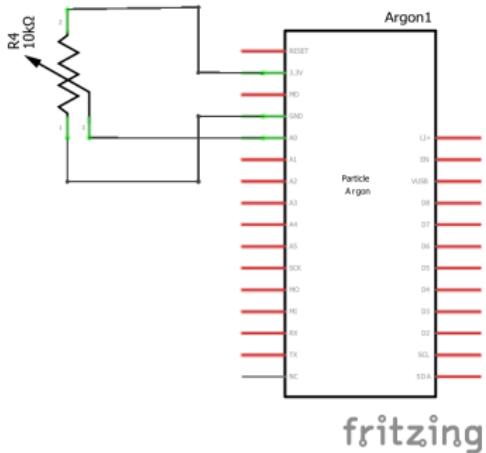


# Basic Structure of Arduino Sketch with Functions

```
1  /*
2   * This is an example of how to use functions
3   * The code below converts inches to feet
4   */
5
6 const int INCHPIN=14;
7 int inches;
8 float feet;
9
10 float inchestoFeet(int measurement);
11
12 void setup() {
13     Serial.begin(9600);    // Turn on Serial Monitor
14     while(!Serial);        // Wait for Serial Monitor to be running
15     pinMode(INCHPIN,INPUT);
16 }
17
18 void loop() {
19     inches = analogRead(INCHPIN);
20     feet = inchestoFeet(inches);
21     Serial.printf("%i inches equal %0.2f feet \n",inches, feet);
22     delay(1000);
23 }
24
25 float inchestoFeet(int measurement) {
26     float answer;           // declare answer as a local variable
27
28     answer = measurement / 12.0;
29     return answer;
30 }
```



Assignment L03\_05\_AnalogInput\_Revisited



- ① Modify your code by adding a function, `intoVolts()`, that converts the analog input value to voltage.
  - ② Print both the raw `analogInput` and the associated voltage to your screen.

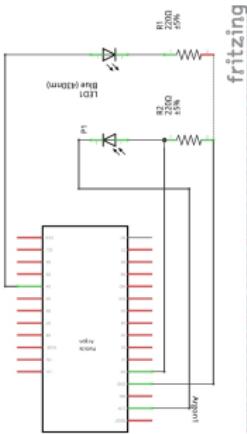


# Photodiode

| PARAMETERS     | DIODE   | PHOTODIODE  |
|----------------|---|---|
| Definition     | A diode is two terminal device which conducts when it is forwards biased. | A photodiode is a two terminal device which conducts when it is reversed biased.                              |
| Circuit symbol |   |   |
| Main Function  | Diode is mainly used as a switch.   | Photodiode is used for conversion of light energy into electrical energy.                                     |
| Material Used  | Germanium or silicon, any of these two can be used.                       | Silicon is used for manufacturing photodiode. An anti-reflective layer of Silver Nitride is used for coating. |
| Applications   | Used in clippers, clampers, rectifiers etc.                               | Used in optoelectronic device, camera, optocouplers etc.  |



# Assignment: L03\_06\_HelloNightLight



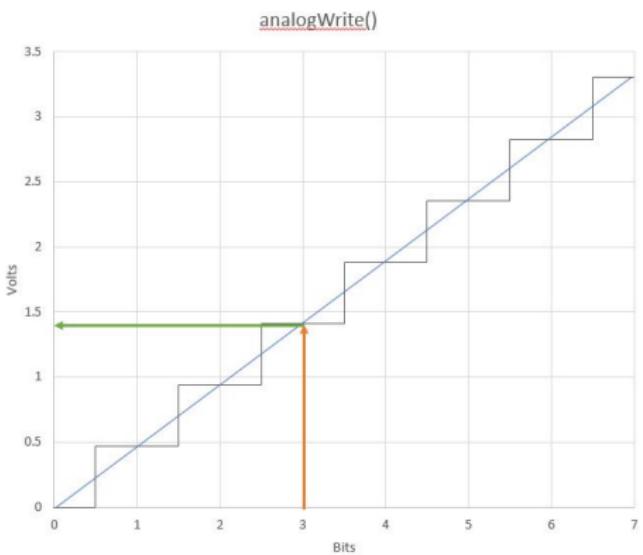
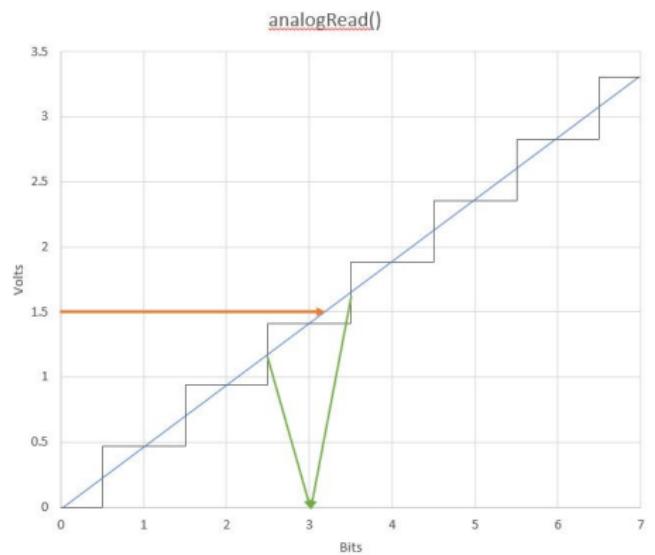
## ① L03\_06\_HelloNightLight

- The anode of the photodiode is connected to Pin A1. Note, unlike an LED, the cathode (short pin) of the photodiode is connected to 3.3V.
- The LED anode to Pin D4.
- Using analogRead/digitalWrite, turn on the LED when the photodiode is dark.
- Using analogWrite, turn on the LED slowly as the room darkens.

- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

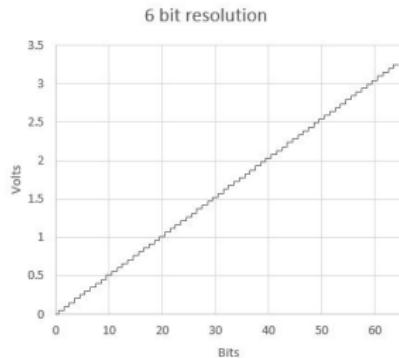
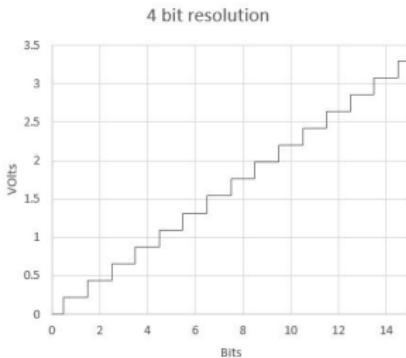
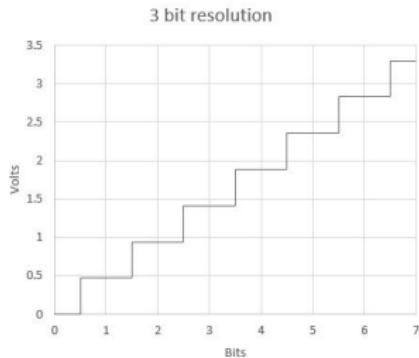


# Analog Resolution - ADC





# Analog Resolution - DAC

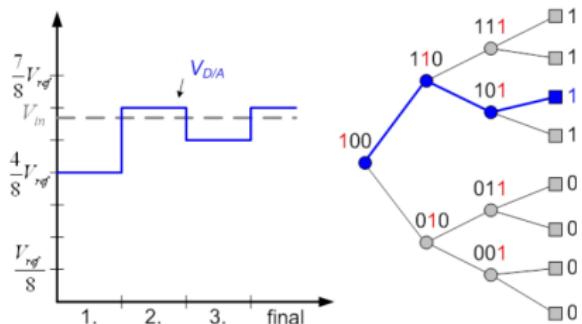
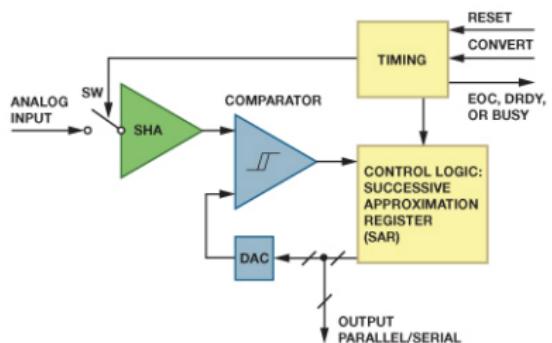


`analogWrite()` resolution can be modified between 2 and 31 bits.

```
1 analogWriteResolution(pin, bits);
```



# Analog Resolution - ADC





# Particle Publish

One of the advantages of the Argon is seamless publishing to the Cloud.

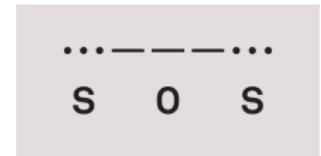
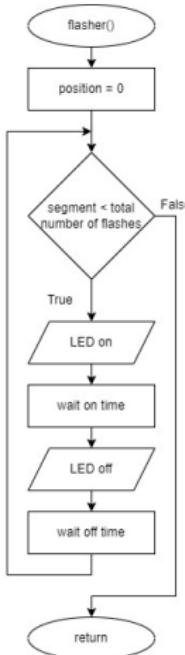
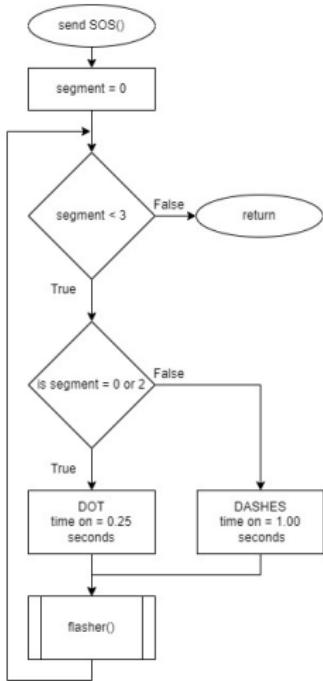
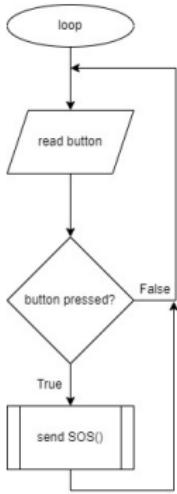
| PARTICLE CLOUD            |                             |                   |                       |
|---------------------------|-----------------------------|-------------------|-----------------------|
| EVENTS                    | VITALS                      | HEALTH CHECK      |                       |
|                           |                             | Search for events | ADVANCED              |
| NAME                      | DATA                        | DEVICE            | PUBLISHED AT          |
| particle/device/update... | false                       | Lalonde           | 10/3/20 at 1:21:01 pm |
| spark/device/diagnos...   | {"device": "network", "s... | Lalonde           | 10/3/20 at 1:21:00 pm |
| spark/device/app-hash     | B665BEE9CD4ABE92IE3...      | Lalonde           | 10/3/20 at 1:21:00 pm |
| Humidity                  | 42.000000                   | Lalonde           | 10/3/20 at 1:20:58 pm |
| Pressure                  | 29.780001                   | Lalonde           | 10/3/20 at 1:20:58 pm |
| Temperature               | 69.129997                   | Lalonde           | 10/3/20 at 1:20:58 pm |
| particle/device/update... | false                       | Lalonde           | 10/3/20 at 1:20:58 pm |
| particle/device/update... | true                        | Lalonde           | 10/3/20 at 1:20:58 pm |
| spark/device/last_reset   | dfu_mode                    | Lalonde           | 10/3/20 at 1:20:58 pm |
| spark/status              | online                      | Lalonde           | 10/3/20 at 1:20:58 pm |

```
1 float temp, prs, hum;    // BME280 variables
2 String Temp, Prs, Hum;   // Strings to hold BME280 values
3
4 void loop() {
5     Temp = String(temp);
6     Prs = String(prs);
7     Hum = String(hum);
8     Particle.publish("Temperature", Temp, PRIVATE);
9     Particle.publish("Pressure", Prs, PRIVATE);
10    Particle.publish("Humidity", Hum, PRIVATE);
11 }
```

Modify L03\_06\_NightLight to publish the photodiode and LED values to the Particle Cloud once every 2 seconds.



# Optional Week 1 Review: L03\_00\_SOS



- Flowchart is in english, not code syntax
- Wire one button and one LED to your Argon
- Declare the appropriate global variables and constants
- First function: void sos
- Second function: void flasher with parameters number of flashes, on time, off time between flashes
- Variables within the functions should be local, not global

## Module 4 - NeoPixels

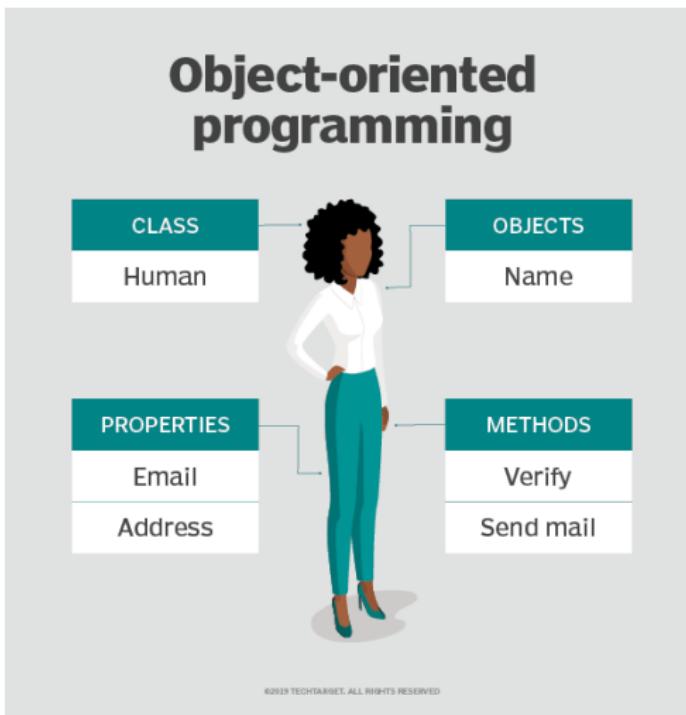


# Smart Communities



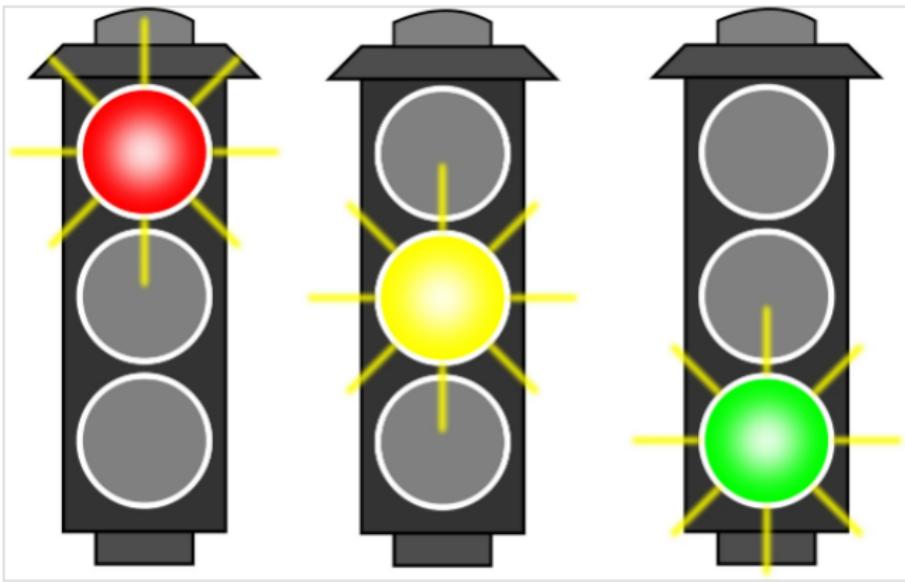


# Objects





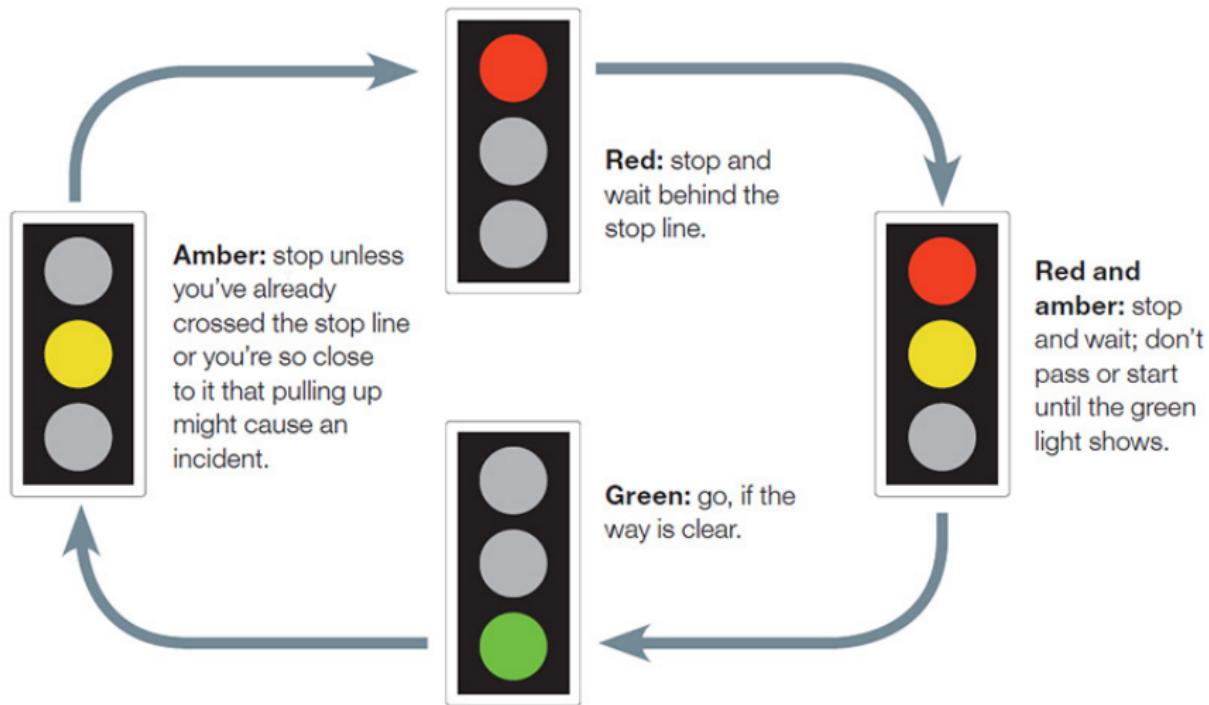
# Traffic Light



Let's use the traffic light to build our own Objects.



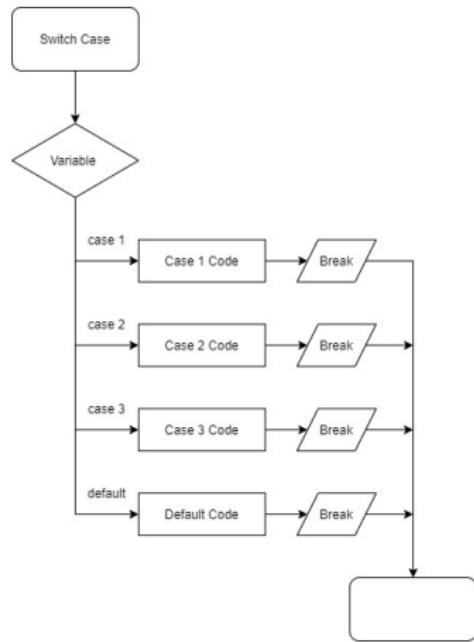
# State Machine - Traffic Lights, British Style





# SWITCH...CASE syntax - multiple IFs

```
// SWITCH...CASE syntax
switch (variable) {
    case constant1:
        // statements
        break;
    case constant2:
        // statements
        break;
    case constant3:
        // statements
        break;
    default:
        // statements
        break;
}
```



The variable is compared to the constants and the applicable code is called. If variable doesn't match any of the constants, then the default case is called.



## Enumeration (enum)

The C-language has a user-defined datatype, enum, which allows the user to create a variable with various names for each of its states.

- Within the enum declaration descriptive tags are used.
- Then the compiler assigns the tags an integer value.

```
1 // Datatype State: the four traffic light states
2 enum State{
3     GREEN,
4     YELLOW,
5     RED,
6     RED_YELLOW
7 };    //note the ; after the }
```

The compiler treats enum as your personal variable type. For example, the enum variable (e.g., State) can now be used within switch...case statements.



# Preprocessor commands

The C-compiler preprocessor executes the `#` commands before converting the program into code the microcontroller can understand.

We have previously used the `#include` preprocessor command. Now, we will learn a few more:

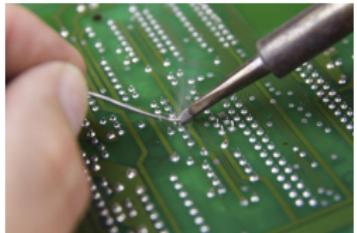
```
1 #ifndef _BUTTON_H_    //if not defined, then execute the rest of code
2
3 #define _BUTTON_H_ //define the label
4
5 // Place your Header.h code here
6
7#endif // _BUTTON_H_
```

- `#ifndef` - if the label is not defined, then execute code until `#endif`
- `#define` - define the label
  - the `#define` label can be set to a value
  - the compiler then replaces the label with the value where ever it sees it meaning it is similar to `const <datatype> = <value>`.
  - NOTE: we will use the CONSTANT and not the `#define`



# Soldering

Soldering is one of the most fundamental skills needed to construct IoT devices.



- Solder the Noun: the alloy (a substance composed of two or more metals) that typically comes as a long, thin wire in spools or tubes
- Solder the Verb: to join together two pieces of metal in what is called a solder joint.

So, we solder with solder!



# Soldering

- Lead vs Lead-free: Traditionally, solder was composed of mostly lead (Pb), tin (Sn), and a few other trace metals. However, lead is hazardous in large quantities.
  - Lead solder has superior properties - lower melting point, flows well, less internal flaws after cooling.
  - Lead-free solder has a higher melting point and thus needs assistance to flow. Many have flux core, a chemical that aids in the flowing.
- Solder flux: Flux is a chemical cleaning agent used before and during the soldering process of electronic components. The flux also protects the metal surfaces from re-oxidation during soldering and helps the soldering process by altering the surface tension of the molten solder.





# Solder Irons



- Solder tips - the tip transfers heat, raising the temperature of the metal components to the melting point of the solder. They come in a variety of shapes and sizes.
- Wand - the wand holds the tip and may have a separate base. The wand controls the temperature of the tip. The temperature range depends on the type of solder.
  - Lead solder - 600°-650°F (316°-343°C)
  - Lead-free solder - 650°-700°F (343°-371°C)
- Brass Sponge - During soldering the tip will start to oxidize, it will change color and less readily accept solder. The brass sponge will reduce buildup. Alternatively, a wet sponge can be used.



# Solder Tip Care



## CLEANING YOUR TIPS

To clean your tips, use either **brass** or **stainless steel wool**. Brass wool is softer and less abrasive, while the harder stainless steel wool has a longer life. After cleaning, immediately wet the tip with fresh solder to prevent oxidation.

## TINNING YOUR TIPS

Tinning stops your tips from oxidizing by creating a **protective layer** between the air and the iron. Preventing oxidation through tinning **extends the life** of your tips.



OXIDIZED TIP



TINNED TIP

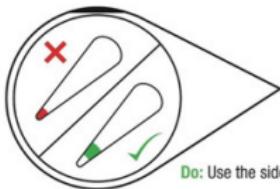


## Properly Storing Tips

If storing your tips for an extended period, you should **clean** and **tin** them before putting them away, which will help prevent them from oxidization. After letting them cool, you may also want to **store them in a sealed container** to further protect them from oxidation, humidity and contamination.



# Good vs Bad Solder Joints



**Don't:** Use the very tip of the iron.  
**Do:** Use the side of the tip of the iron, "The Sweet Spot."



**Do:** Touch the iron to the component leg and metal ring at the same time.



**Do:** While continuing to hold the iron in contact with the leg and metal ring, feed solder into the joint.



**Don't:** Glob the solder straight onto the iron and try to apply the solder with the iron.



**Do:** Use a sponge to clean your iron whenever black oxidation builds up on the tip.



**A** Solder flows around the leg and fills the hole - forming a volcano-shaped mound of solder.



**B** Error: Solder balls up on the leg, not connecting the leg to the metal ring.  
Solution: Add flux, then touch up with iron.



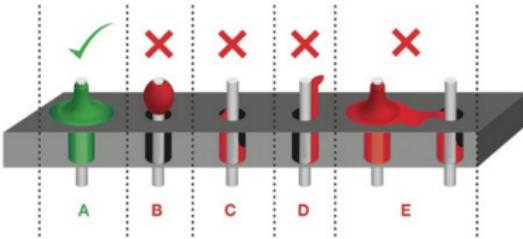
**C** Error: Bad Connection (i.e. it doesn't look like a volcano)  
Solution: Flux then add solder.



**D** Error: Bad Connection...and ugly...oh so ugly.  
Solution: Flux then add solder.

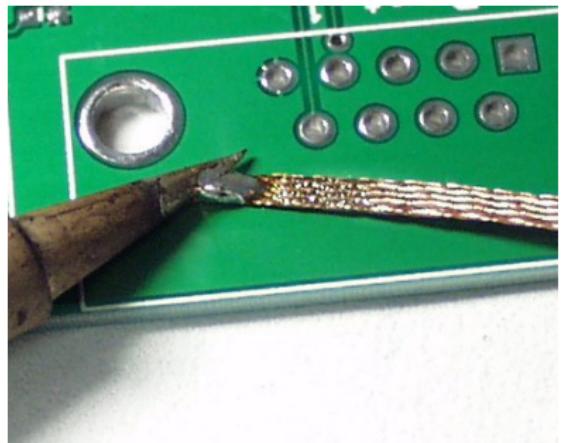


**E** Error: Too much solder connecting adjacent legs (aka a solder jumper).  
Solution: Wick off excess solder.

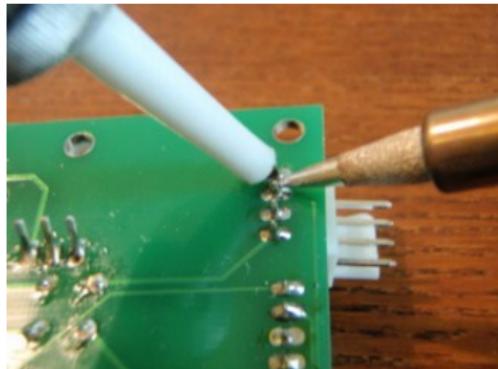




# Desoldering



Solder Wick



Desoldering Pump



# Generating Random Numbers

```
1  /*
2   * The random() function generates pseudo-random
3   * numbers.
4   *     random(min,max)
5   *     random(max)      //assumes min = 0
6   * returns a number between min and max-1
7   */
8
9 // print a random number from 0 to 299
10 randomNumber = random(300);
11 Serial.printf("The number is = %i \n",randomNumber);
12
13 // print a random number from 10 to 19
14 randomNumber = random(10, 20);
15 Serial.printf("The number is = %i \n",randomNumber);
```



# Nested Statements



- Loops and conditions can be nested within each other
- A nested loop is a loop within a loop, an inner loop within the body of an outer one. How this works is that the first pass of the outer loop triggers the inner loop, which executes to completion. Then the second pass of the outer loop triggers the inner loop again. This repeats until the outer loop finishes.
- The break command can be used to exit a loop before completion

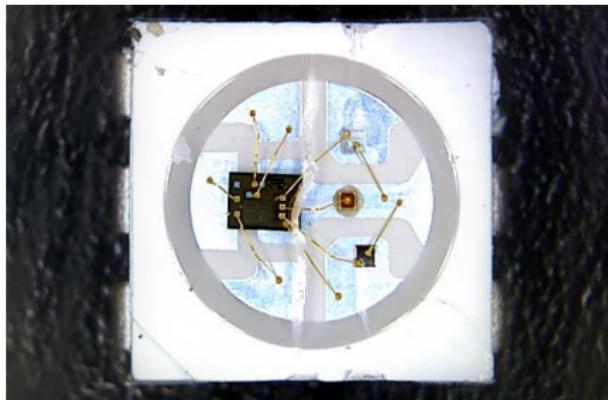


# Nested For Loops

```
1 int tens;
2 int ones;
3
4 // Nested FOR Loops
5 for(tens=0;tens<10;tens++) {
6     for(ones=0;ones<10;ones++) {
7         Serial.printf("Combining %i(tens) and %i(ones) gives %i%i\n",tens,ones,tens,ones);
8     }
9 }
10
11 // An IF nested in Nested FOR Loops
12 for(tens=0;tens<10;tens++) {
13     for(ones=0;ones<10;ones++) {
14         if(tens != ones) {
15             Serial.printf("Combining %i(tens) and %i(ones) gives %i%i\n",tens,ones,tens,ones);
16         }
17     }
18 }
19
20 // Using break to break out of a loop
21 for(tens=0;tens<10;tens++) {
22     for(ones=0;ones<10;ones++) {
23         Serial.printf("Combining %i(tens) and %i(ones) gives %i%i\n",tens,ones,tens,ones);
24         if((tens+ones) = 10) {
25             break;
26         }
27     }
28 }
```



# NeoPixels

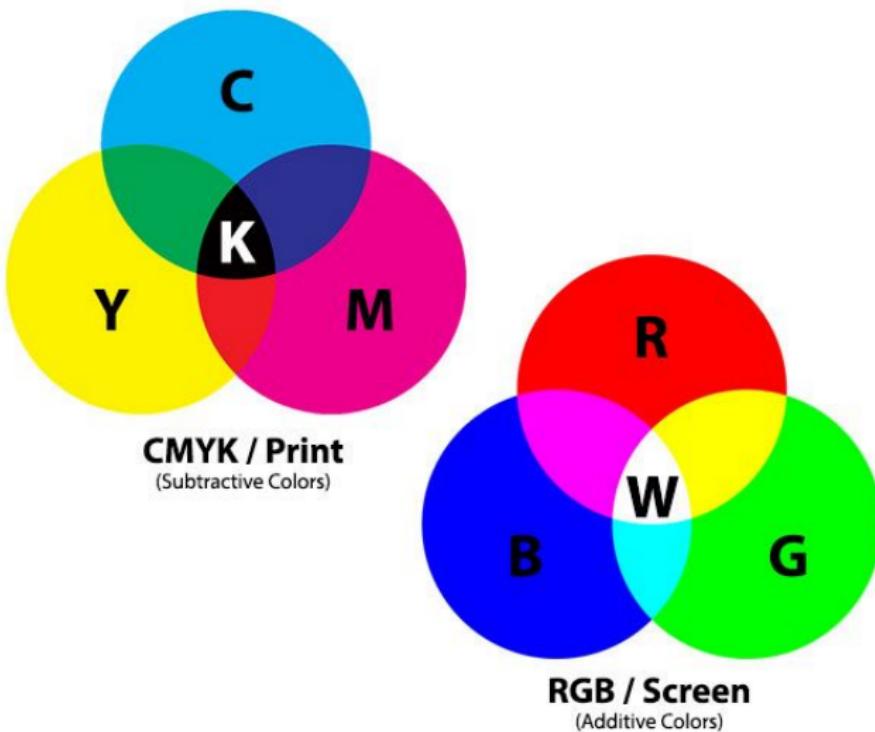


NeoPixels are:

- Addressable RGB LEDs based on the WS2812 (or WS2811) LED/drivers.
- They come as individual pixels, in strips, in matrices, rings, etc.
- They can be programmed via your microcontroller to create a wide array of effects and animations.

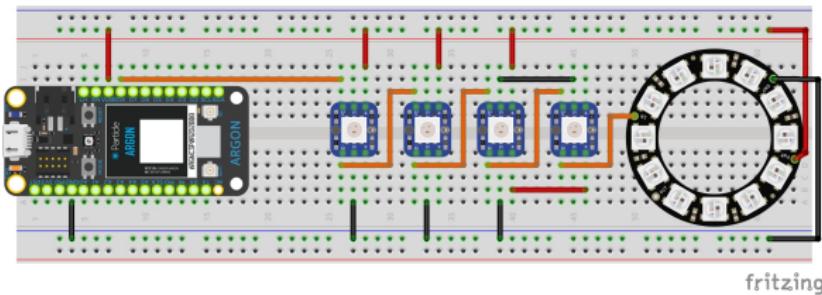


# CYMK vs RGB Colors

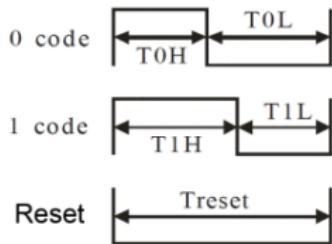




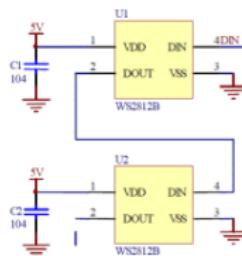
# NeoPixel Programming



WS2812 Protocol



LED-Chain



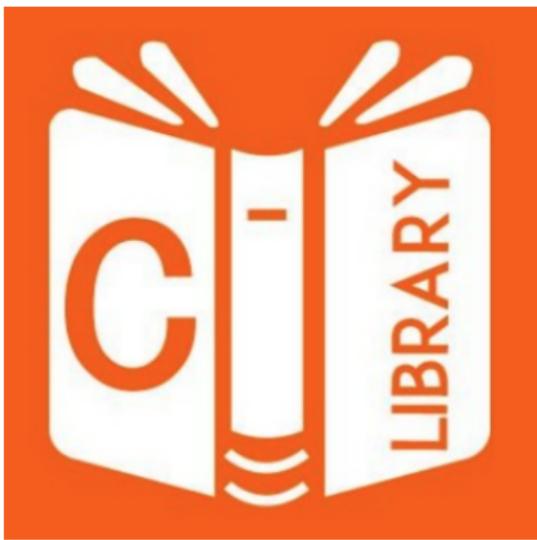


# Using NeoPixel Class and Methods

```
1 #include <neopixel.h>
2
3 const int PIXELPIN = D8;      // Pin the NeoPixels are connected to
4 const int PIXELCOUNT = 16;    // Total number of NeoPixels
5
6 Adafruit_NeoPixel pixel(PIXELCOUNT, PIXELPIN, WS2812B); //declare object
7 /* Argument 1 = Number of pixels
8 * Argument 2 = GPIO pin number
9 * Argument 3 = Pixel type flags, add together:
10 * Use:
11 *   WS2811        // 400 KHz datastream (NeoPixel)
12 *   WS2812        // 800 KHz datastream (NeoPixel)
13 *   WS2812B       // 800 KHz datastream (NeoPixel)
14 *   WS2813        // 800 KHz datastream (NeoPixel)
15 *   WS2812B2      // 800 KHz datastream (NeoPixel)
16 *   SK6812RGBW    // 800 KHz datastream (NeoPixel RGBW)
17 */
18 void setup() {
19   pixel.begin();
20   pixel.show(); //initialize all off
21 }
22
23 void loop() {
24   pixel.setPixelColor(n, red, green, blue); // n is the pixel number being set
25   pixel.setPixelColor(n, color);           // red,green,blue = 0 - 255
26   pixel.setBrightness(bri);              // hex code 0x000000 - 0xFFFFFFFF
27   pixel.show();                         // 0 - 255
28   pixel.show();                         // nothing changes until show()
29   pixel.clear();                       // even clear() needs a show()
30 }
```



# Installing Libraries

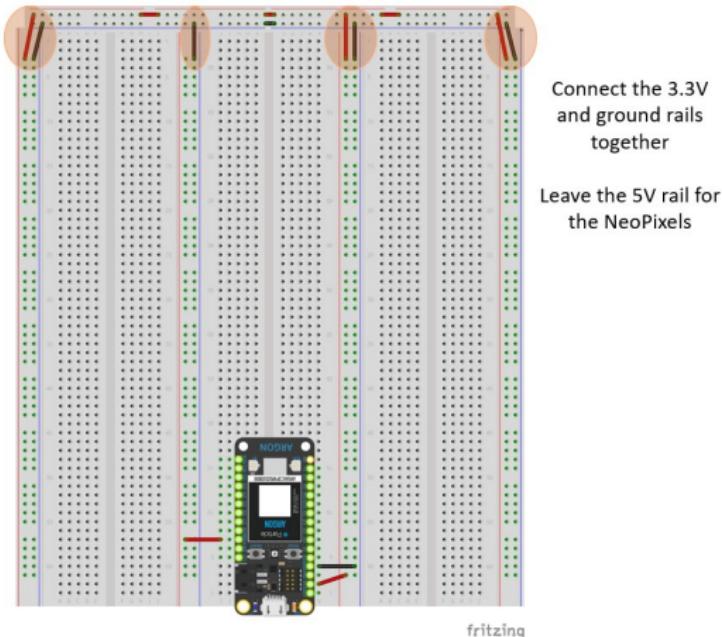


Using the Command Palette within VSCode:

- `ctrl-shift-p` → Particle: Find Libraries
- `ctrl-shift-p` → Particle: Install Library

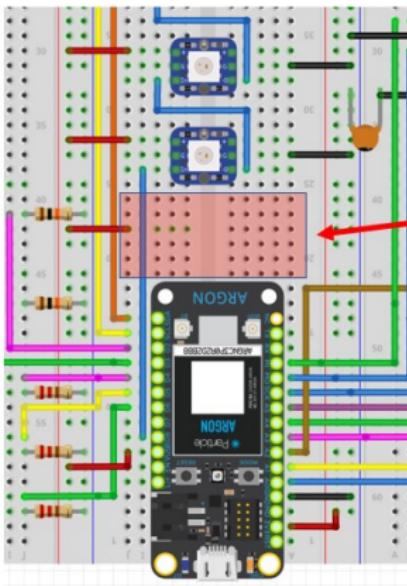


# Move to Big Breadboard





# Leave Space for Future Components



Leave Open  
for Future  
Components



# Assignment: NeoPixels



- Notebook: flowchart
- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

## ① L04\_01\_neoPixel

- Using FOR loop and individual R/G/B, light up 16 pixels; small delay between.

## ② L04\_02\_colorHeader

- Implement a header file that contains the pixel colors.

## ③ L04\_03\_neoStrip, use setPixelColor() to implement functions:

- Send a pixel of a random color down and back on the strip.
- Light the strip up as a rainbow.
- Send a pair of Maize and Blue lights down the strip.

## ④ L04\_04\_pixelFill, create a function:

- to light up a partial segment.
- light 7 segments of different colors.



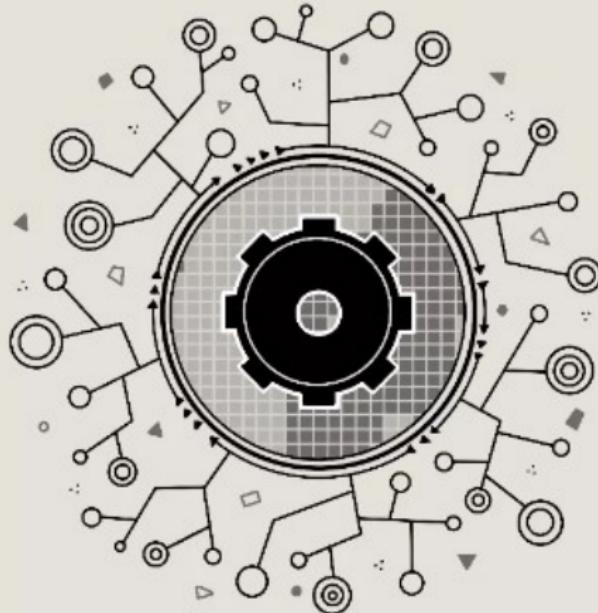
## RandomSeed()

- The "pseudo" in pseudo-random indicates it is not truly random.
- randomSeed() initializes the pseudo-random number generator causing it to start at an arbitrary point in its random sequence. This sequence, while very long, and while appearing random, is always the same.
- If it is important for a sequence of values generated by random() to differ, on subsequent executions, use randomSeed() to initialize the random number generator with a fairly random input, such as an analogRead() on an unconnected pin.

```
1 // Leave an Analog Input (A0) floating
2 pinMode(A0, INPUT);
3 randomSeed(analogRead(A0));
4
5 // print a random number hex color value
6 randNumber = random(0x0000,0xFFFFFFF);
7 Serial.printf("My color is 0x%06X \n",randNumber);
```



# Algorithms



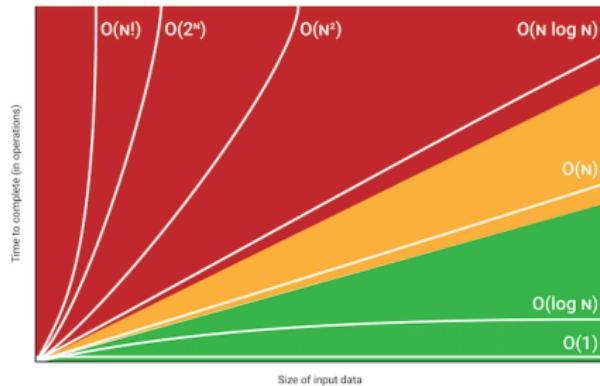
## Algorithm

[*'al-gə-ri-thəm*]

A set of instructions for solving a problem or accomplishing a task.



# Big O Notation



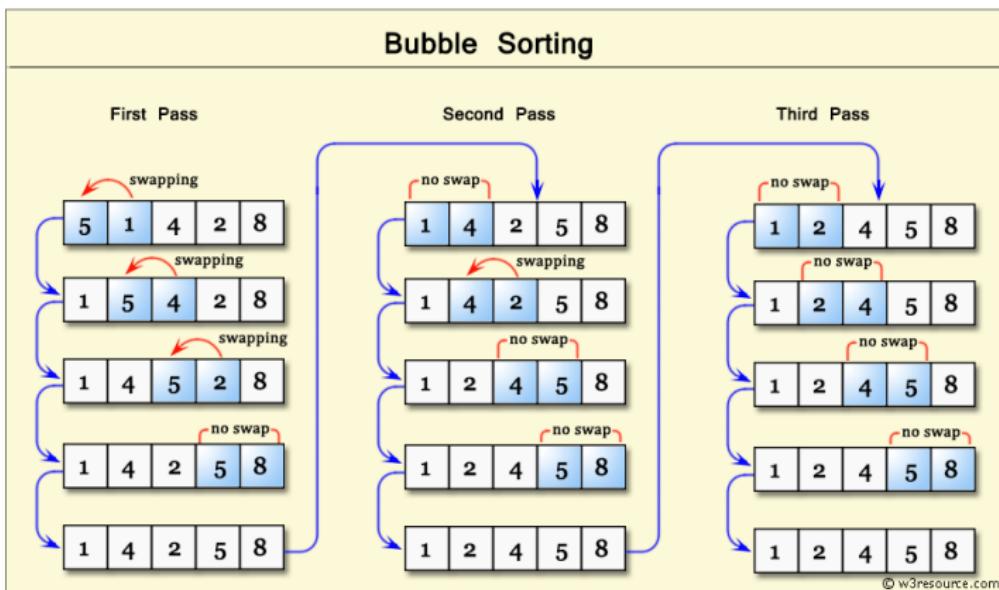
Big O notation is a way to describe the speed or complexity of a given algorithm.

- Big O notation tells the number of operations an algorithm will make.
- It gets its name from the literal "Big O" in front of the estimated number of operations.
- Big O establishes a worst-case run time



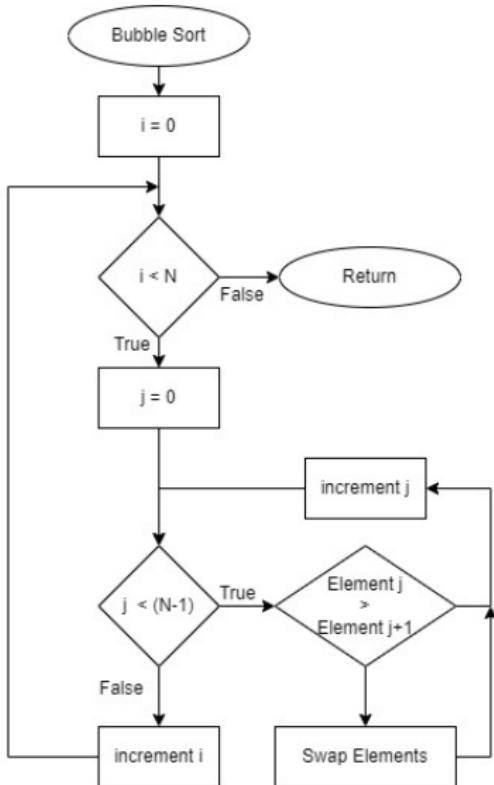
# Bubble Sort

## Bubble Sorting





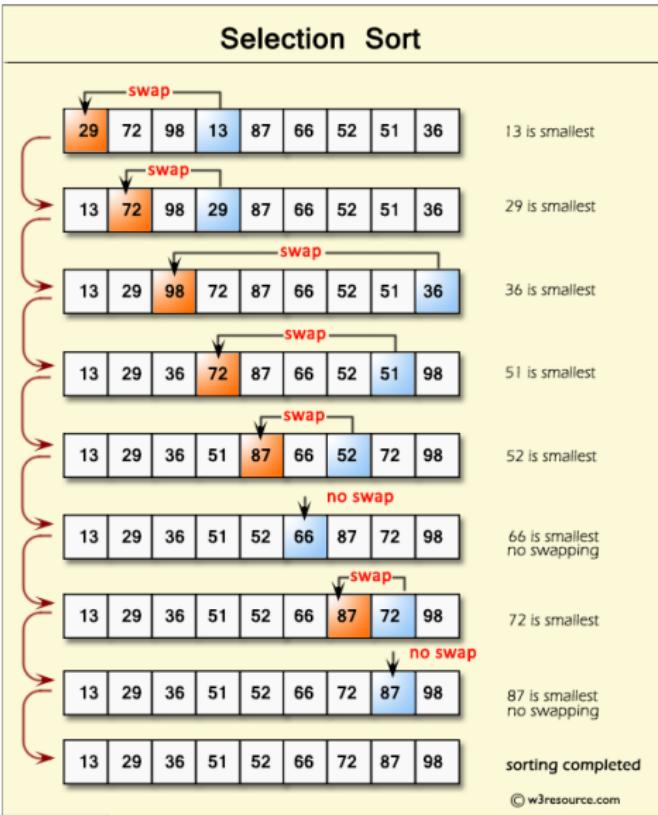
# Bubble Sort Algorithm - $O(n^2)$



- Larger elements are swapped (one-by-one) with smaller ones (i.e., they float to the top)
- Takes  $O(n^2)$  iterations as there is a  $(N - 1)$  loop nested in a  $N$  loop.

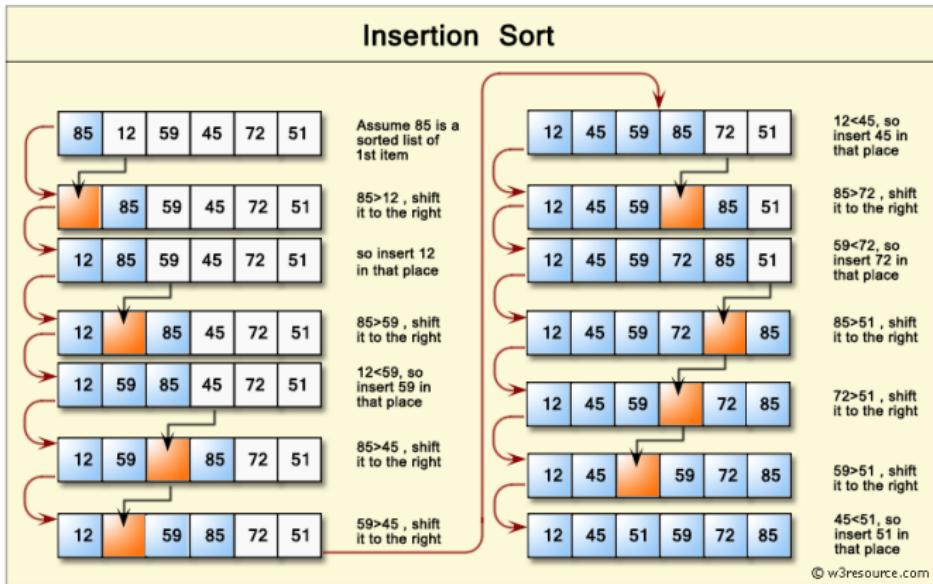


# Selection Sort



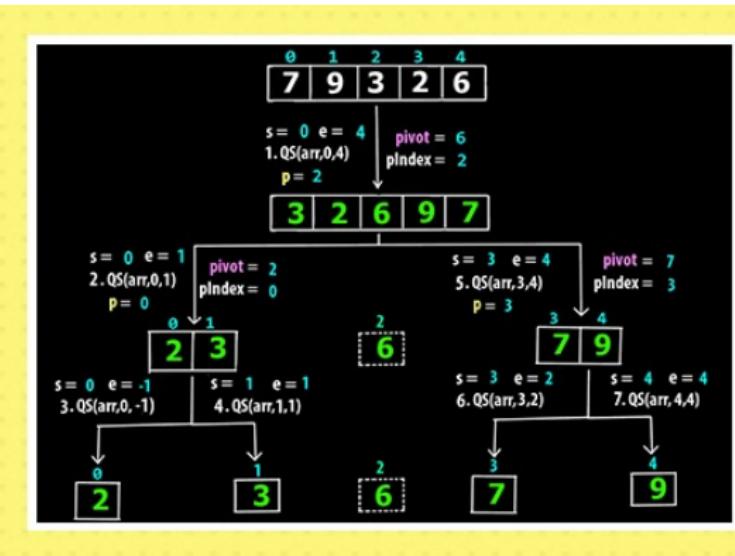


# Insertion Sort





# Quick Sort

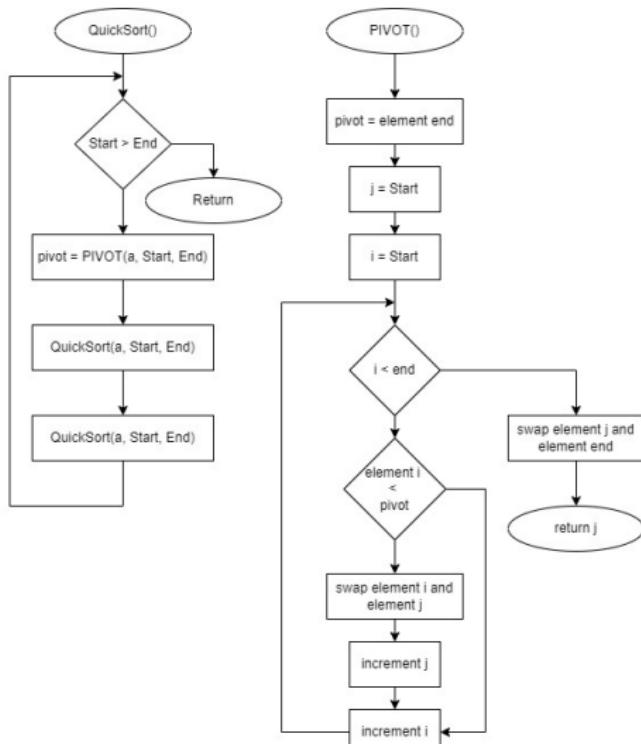


# QUICK SORT ALGORITHM

```
QuickSort(arr[], s, e)
{
    if(s < e)
    {
        p = Partition(arr[], s, e)
        QuickSort(arr[], s, (p-1))
        QuickSort(arr[], (p+1), e)
    }
}
```



# Quick Sort Algorithm - $O(n \log(n))$



- Any pivot point is selected (in this case, the last element)
- Smaller elements are put to the left of the pivot, larger to the right.
- Each side of the pivot is then sorted using the same method. This is called recursion.
- This continues until everything is sorted.
- In general, this takes  $O(n \log(n))$  iterations



# Quick Sort Algorithm - $O(n \log(n))$

```
1 int partition (int arr[], int low, int high) {
2     int pivot = arr[high];
3     int i = (low - 1);
4     int swap;
5
6     for (int j = low; j <= high- 1; j++)      {
7         if (arr[j] <= pivot)                  {
8             i++;
9             swap = arr[i];
10            arr[i] = arr[j];
11            arr[j] = swap;
12        }
13    }
14    swap(&arr[i + 1], &arr[high]);
15    return (i + 1);
16 }
17
18 void quickSort(int arr[], int low, int high) {
19     if (low < high)      {
20         int pi = partition(arr, low, high);
21
22         quickSort(arr, low, pi - 1);
23         quickSort(arr, pi + 1, high);
24     }
25 }
```



# Assignment: L04\_05\_sorting



- Notebook: flowchart
- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code
  
- Randomly fill an array of length equal to number of neopixels with colors from blue to red.
- Implement a function for the bubble sort that displays the change in the array after each iteration.
- Implement either the selection or insertion sort on a new random array
- (Optional) implement the quicksort

## Module 5 - Encoders



# IoT Humor

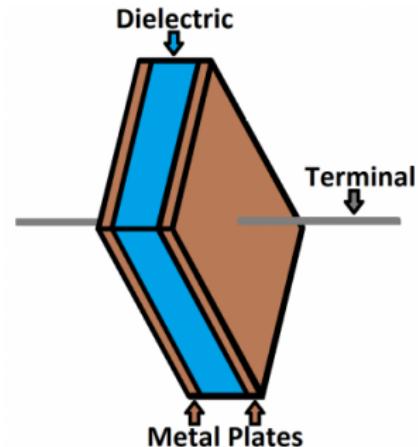




# Capacitors

A capacitor is created out of two metal plates and an insulating material called a dielectric. The metal plates are placed very close to each other, in parallel, but the dielectric sits between them to make sure they don't touch.

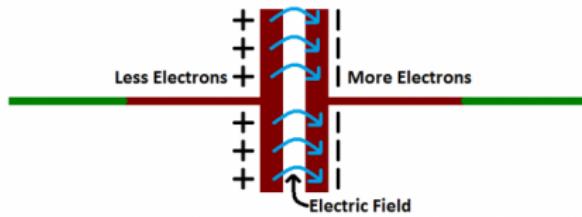
- The dielectric can be made out of all sorts of insulating materials; paper, glass, rubber, ceramic, plastic, or anything that will impede the flow of current.
- The plates are made of a conductive material; aluminum, tantalum, silver, or other metals.





# Capacitors

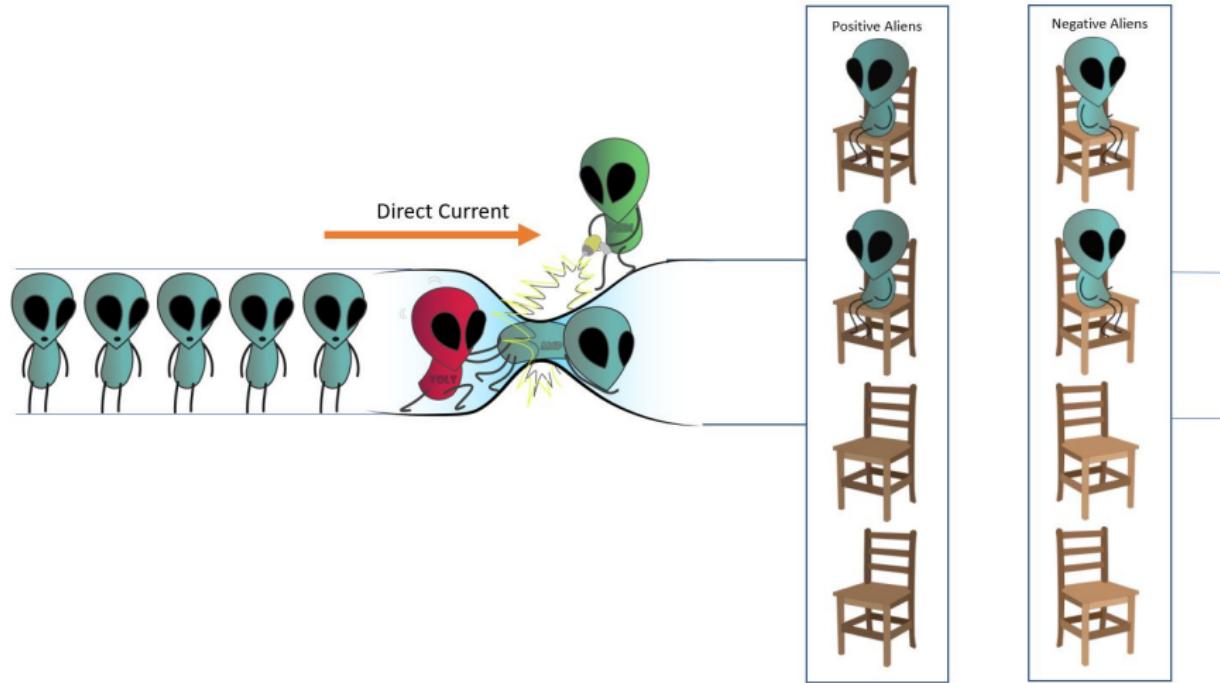
When current flows into a capacitor, the charges get "stuck" on the plates because they cannot get past the insulating dielectric. Electrons build up on one of the plates, and it becomes overall negatively charged. The large amount of negative charges pushes away like charges on the other plate, making it positively charged.



The stationary charges on these plates create an electric field, which influences electric potential energy and voltage. When charges group together on a capacitor like this, the capacitor is storing electric energy just as a battery might store chemical energy.



# Capacitors in Circuits

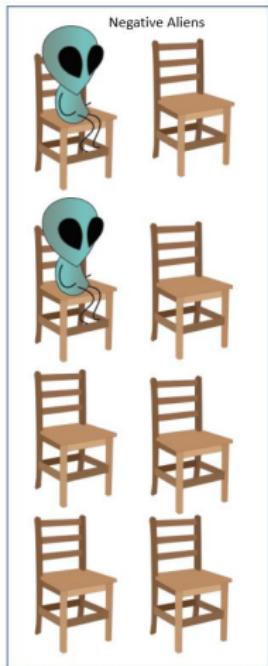
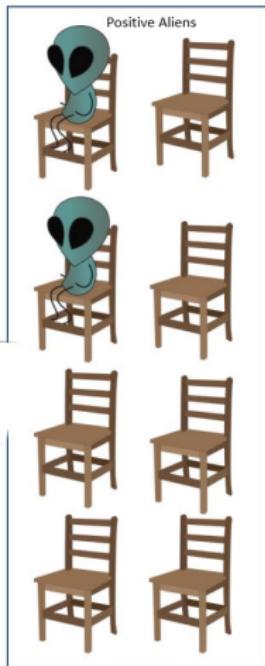
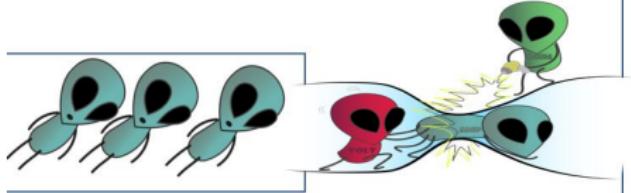




# Capacitors in Circuits

Larger values of R and C

Direct Current





# RC Time Constant

Capacitance is defined as:

$$C = \frac{Q}{V} \left( \frac{\text{Coulombs}}{\text{Volt}} \right)$$

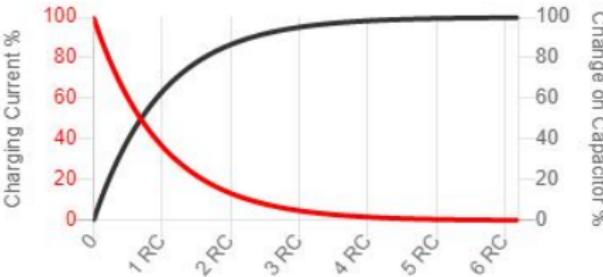
The current through a capacitor is:

$$I = C \frac{\Delta V}{\Delta t}$$

And, therefore, the capacitor charges with a time constant ( $\tau$ ):

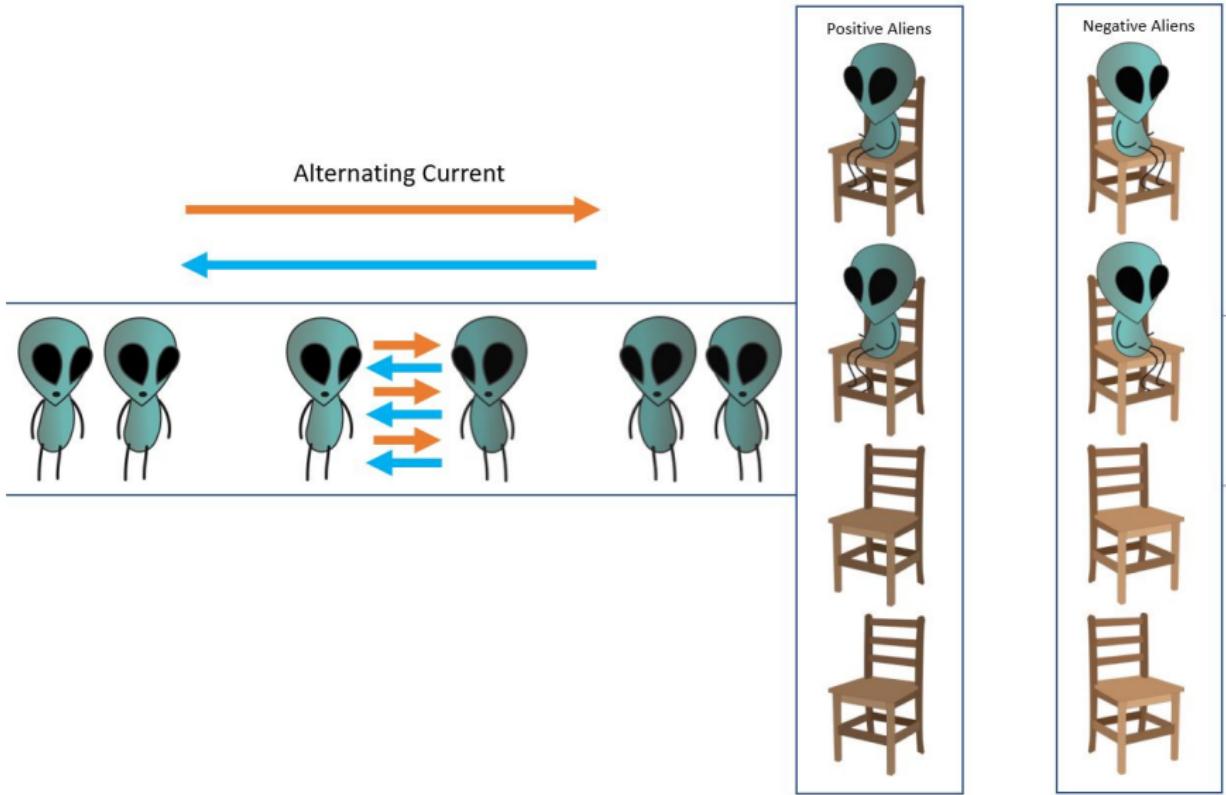
$$\tau = RC$$

$$V_c(t) = V_c(0) * e^{-\frac{t}{\tau}}$$





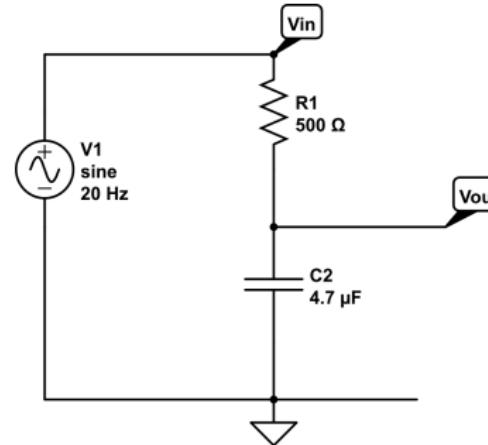
# Alternating Current





# Low Pass Filter - cutoff frequency $f_c$

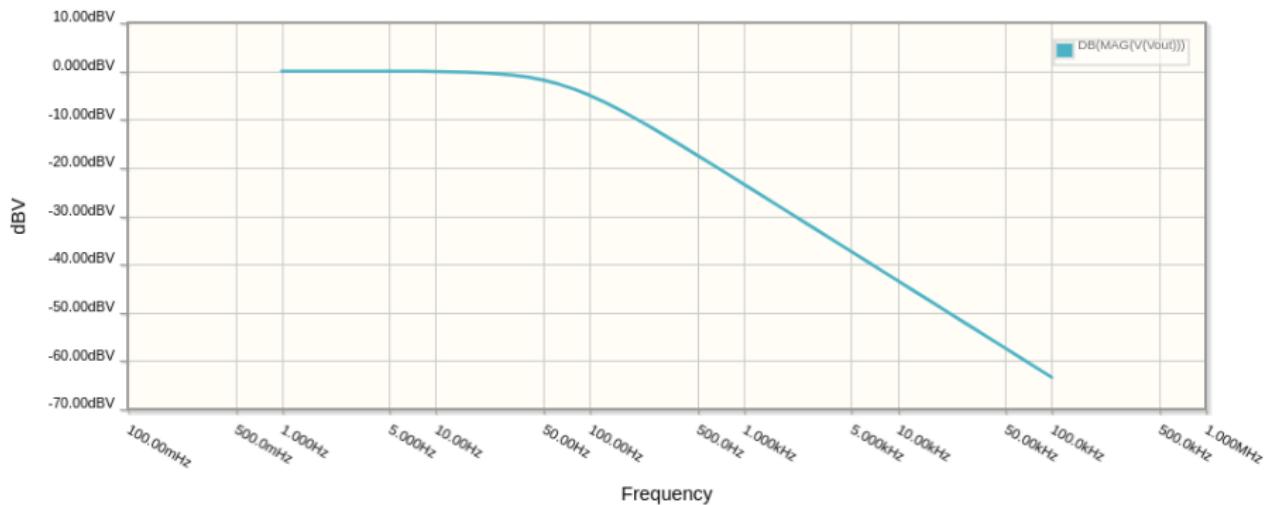
- At low frequencies, there is plenty of time for the capacitor to charge up to practically the same voltage as the input voltage.
- At high frequencies, the capacitor only has time to charge up a small amount before the input switches direction. The output goes up and down only a small fraction of the amount the input goes up and down. At double the frequency, there's only time for it to charge up half the amount.



$$f_c = \frac{1}{2\pi\tau} = \frac{1}{2\pi RC}$$



# Low Pass Filter Response



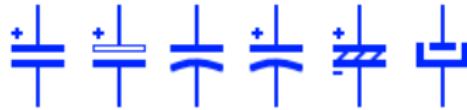
$$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi(500)(4.7 \times 10^{-6})} = 67.5678 \text{ Hz}$$



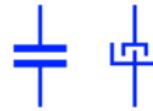
# Capacitors - does it matter how they are placed

- Some types of capacitors (electrolytic and tantalum) are polarized (they have + and - terminals). This is due to how the dielectric film has been deposited. The reverse polarity leads to degradation of the dielectric.
- Other capacitors (ceramic and film) do not have a polarity and can be installed in either direction.

Polarized Electrolytic Capacitor

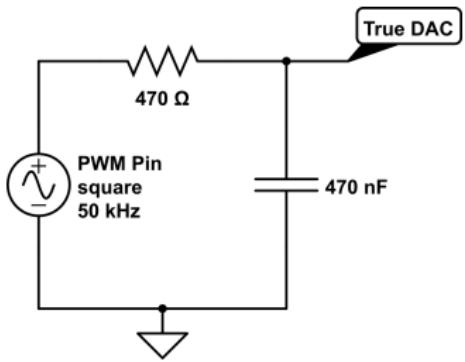


Generic Capacitor





# True DAC on Argon



`analogWrite(pin, value, frequency)`

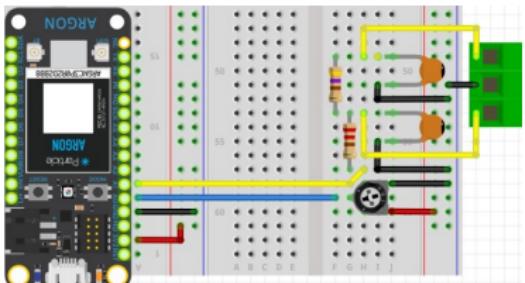
The Particle microcontrollers do not have a true DAC (Digital to Analog Converter). However, we can convert a PWM pin to a DAC signal using a low pass filter.

- The PWM signal oscillates at 500 Hz, but we can increase up to 50,000 Hz using a third parameter in `analogWrite()`.
- Using  $R = 470\Omega$  and  $C = 0.47\mu F$  will give a  $f_c = 720\text{Hz}$ .



# Assignment: Low Pass Filters

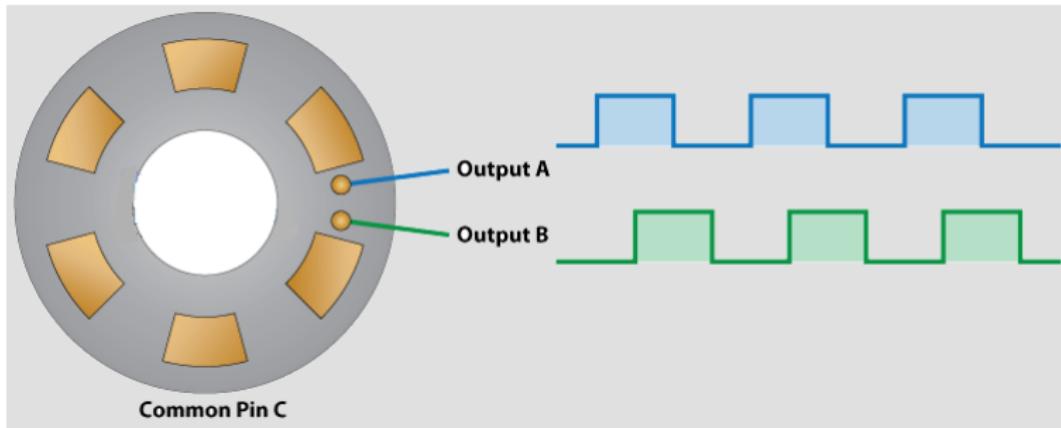
## ① L05\_00\_lowPass



- Notebook:  
schematic
- Fritzing diagram
- Wire your circuit
- Write the code
- Output 0.825V to pin A5 (no wire will be connected to this output).
- Connect a potentiometer to A0. Use it to vary a frequency ( $\nu$ ) from 0 to 500 Hz.
- Create a sine wave of frequency  $\nu$ :  
 $\sin(2\pi\nu t)$  and output on the A1 pin. Set the PWM frequency to 50,000 Hz.
- Create a DAC to convert the PWM signal on A1 to analog using a low pass filter with  $f_c \approx 700\text{Hz}$
- Create a low pass filter with  $f_c \approx 67\text{Hz}$
- Use an oscilloscope to measure the A5, A1, post DAC, and post low-pass filter.
- Record in your notebook how the signals change when  $\nu$  is varied with the potentiometer.

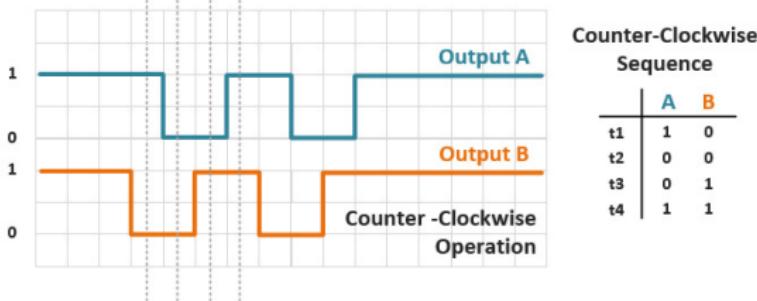
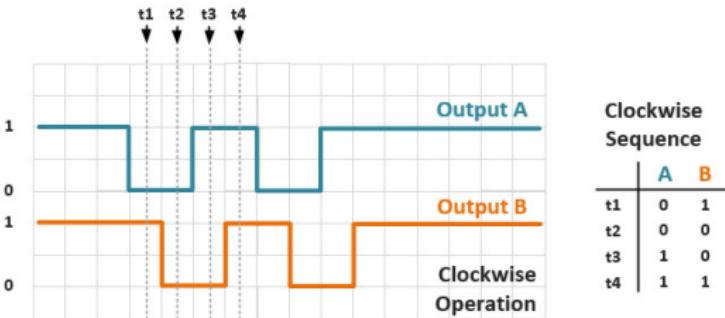


# Encoders





# Encoders



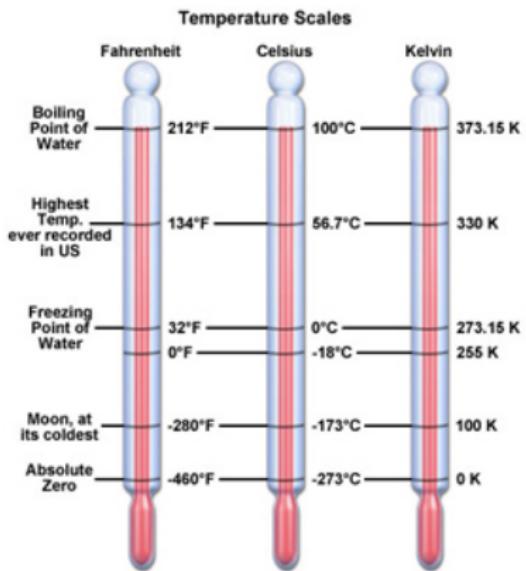


# The Encoder Class

```
1 #include <Encoder.h>
2 Encoder myEnc(PINA, PINB);
3 // The "c" pin on the encoder is connected to GND
4
5 void setup() {
6 }
7
8 void loop() {
9     // read encoder position
10    position = myEnc.read();
11
12    // set encoder to a position
13    myEnc.write(maxPos);
14 }
```



# Mapping (or Converting)



Mapping is the conversion from one set of units to another. For example converting from Celsius to Fahrenheit:

$$Temp(^{\circ}F) = \frac{9}{5} * Temp(^{\circ}C) + 32$$

C++ provides us with a function to do this mapping:

```
newVal = map(value, fromLow,  
fromHigh, toLow, toHigh);
```

For example:

```
tempF = map(tempC,0,100,32,212);
```



# Assignment: Encoders



- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

## ① L05\_01\_encoder

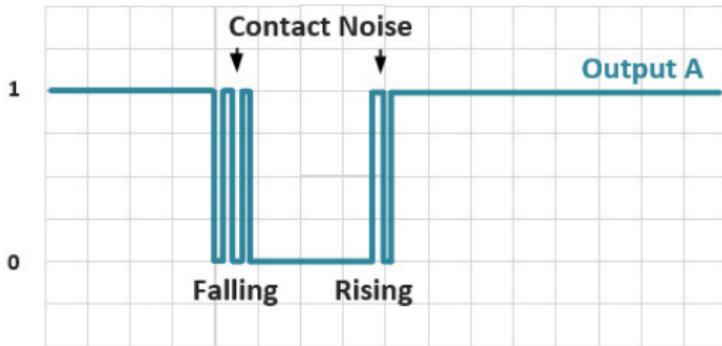
- Display the encoder position to the screen, but only when encoder is moved.
- What do you notice about the encoder position as you turn it slowly?

## ② L05\_02\_NeoPixel

- The encoder has 96 positions. Map the encoder input to 16 NeoPixels.
- Bound the input, so the mapped range is from 0 to 15.
- What is the difference in performance if you bind the input vs the mapped range?
- Use the encoder to light up the four NeoPixels and the ring.

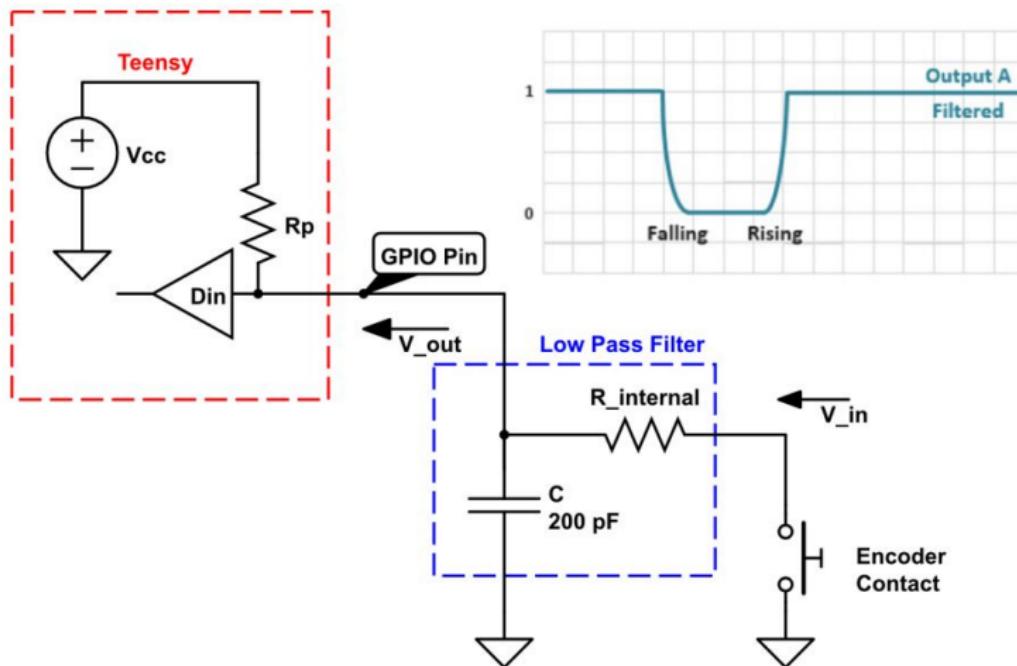


# Encoder Jitter



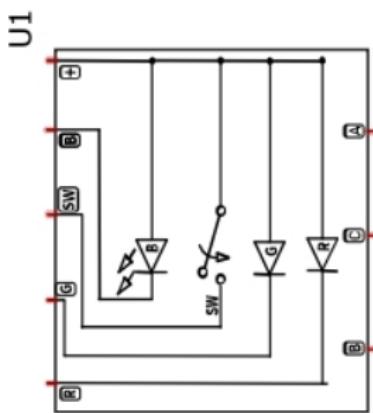


# Encoder - Low Pass Filter





# Encoder - LEDs and Button



fritzing

The encoder has a Red, Green, and Blue LED, as well as a Switch (technically a Button), that act like discrete components and are not associated with the Encoder.h library. Note, the LEDs are active low (the pins need to be set to ground to activate the light).



# Assignment: Encoders



- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

## ① L05\_03\_encoder\_switch

- Connect the encoder switch and LEDs.
- Use the switch to turn on/off the NeoPixels.
- Set encoder LED to red for off and green for on.
- Disable turning the encoder when off.

## ② L05\_04\_rainbow1

- Use a button to cycle the NeoPixel ring colors through the colors of the rainbow; one color change each time button is pressed.

## ③ L05\_05\_rainbow2

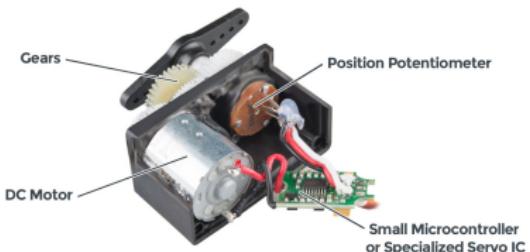
- Have it continuously cycle (i.e., while pressed colors change every one second).

# Module 6 - Servo



# Servo Motors

- A servo is any motor-driven system with a feedback element built in.
- A servo motor basically has three core components:
  - ① a DC motor,
  - ② a potentiometer that measures its position,
  - ③ a feedback controller circuit
- The servo is controlled by a PWM signal from a digital pin. The width of the pulse determines the position that the servo moves to.





# Servo library

The Particle Argon has the Servo class built-in, so no library is needed.

## ① Header

- Servo myServo; - create object myServo of class Servo

## ② void setup()

- myServo.attach(pin) - attach the Servo object to a pin (this must be a PWM pin)

## ③ void loop()

- myServo.write(angle) - move servo to angle (in degrees)



# Assignment: L06\_Servo



## ① L06\_01\_Servo

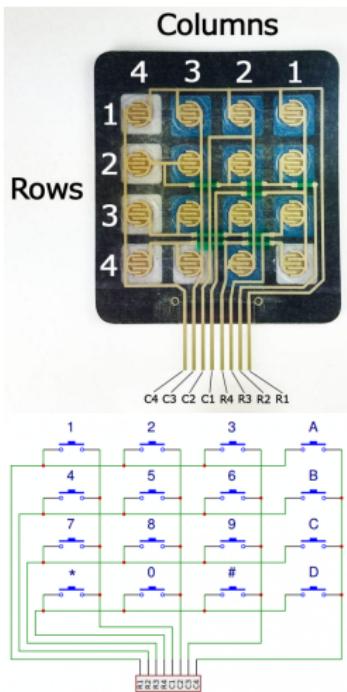
- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

- Connect the servo and a button to the Teensy
- Create a HelloServo-type code that moves the servo to 180 degrees, waits, and then moves it to zero.
- Modify the code to have the servo oscillate between 0 and 180 degrees using a sine wave pattern.
- Have the button to start and stop the motion.
- Extra: Have the motion begin again at the point in the cycle where it stops.

Recall, in C++ (math.h) the math constants are M\_<name>. For example, M\_PI =  $\pi$ .



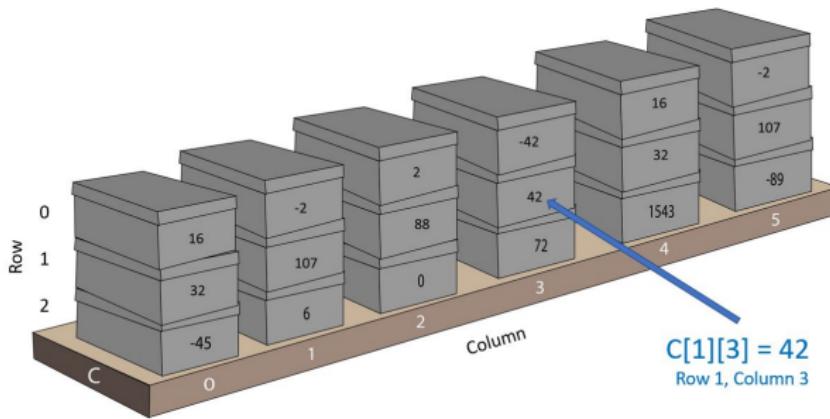
# KeyPad



- The Keypad is a two-dimensional array of buttons.
- Pushing a button connects one row pin with one column pin.
- We will use the Keypad.h library to access the Keypad.
- NOTE: due to the onboard LED, you can not use Pin 13 for the keypad



## 2-dimensional arrays



- Declare Array: `int c[3][6] = {{16,-2,2,-42,16,-2},{32,107,88,42,32,107}, {-45,6,0,72,1543,-89}};`
- Set a Cell: `c[1][3] = 42;`
- Access a Cell: `x = c[1][3]; → x = 42`



# Char and Byte Datatype

- The char data type is a single byte in size and can be used to represent text characters (ASCII).
- Alternatively, the datatype byte can also be used for a single byte (8-bit number)

## ASCII TABLE

| Decimal | Hex | Char                   | Decimal | Hex | Char    | Decimal | Hex | Char | Decimal | Hex | Char  |
|---------|-----|------------------------|---------|-----|---------|---------|-----|------|---------|-----|-------|
| 0       | 0   | [NULL]                 | 32      | 20  | [SPACE] | 64      | 40  | @    | 96      | 60  | `     |
| 1       | 1   | [START OF HEADING]     | 33      | 21  | !       | 65      | 41  | A    | 97      | 61  | a     |
| 2       | 2   | [STOP OF TEXT]         | 34      | 22  | “       | 66      | 42  | B    | 98      | 62  | b     |
| 3       | 3   | [END OF TEXT]          | 35      | 23  | #       | 67      | 43  | C    | 99      | 63  | c     |
| 4       | 4   | [END OF TRANSMISSION]  | 36      | 24  | \$      | 68      | 44  | D    | 100     | 64  | d     |
| 5       | 5   | [ENQ/UART]             | 37      | 25  | %       | 69      | 45  | E    | 101     | 65  | e     |
| 6       | 6   | [ACKNOWLEDGE]          | 38      | 26  | &       | 70      | 46  | F    | 102     | 66  | f     |
| 7       | 7   | [PRINT]                | 39      | 27  | *       | 71      | 47  | G    | 103     | 67  | g     |
| 8       | 8   | [BACKSPACE]            | 40      | 28  | (       | 72      | 48  | H    | 104     | 68  | h     |
| 9       | 9   | [HORIZONTAL TAB]       | 41      | 29  | )       | 73      | 49  | I    | 105     | 69  | i     |
| 10      | A   | [LINE FEED]            | 42      | 2A  | *       | 74      | 4A  | J    | 106     | 6A  | j     |
| 11      | B   | [VERTICAL TAB]         | 43      | 2B  | +       | 75      | 4B  | K    | 107     | 6B  | k     |
| 12      | C   | [FORM FEED]            | 44      | 2C  | ,       | 76      | 4C  | L    | 108     | 6C  | l     |
| 13      | D   | [CARriage RETURN]      | 45      | 2D  | -       | 77      | 4D  | M    | 109     | 6D  | m     |
| 14      | E   | [SOFT DLE]             | 46      | 2E  | =       | 78      | 4E  | N    | 110     | 6E  | n     |
| 15      | F   | [SOH/FN]               | 47      | 2F  | /       | 79      | 4F  | O    | 111     | 6F  | o     |
| 16      | 10  | [DATA LINK ESCAPE]     | 48      | 30  | 0       | 80      | 50  | P    | 112     | 70  | p     |
| 17      | 11  | [DEVICE CONTROL 1]     | 49      | 31  | 1       | 81      | 51  | Q    | 113     | 71  | q     |
| 18      | 12  | [DEVICE CONTROL 2]     | 50      | 32  | 2       | 82      | 52  | R    | 114     | 72  | r     |
| 19      | 13  | [DEVICE CONTROL 3]     | 51      | 33  | 3       | 83      | 53  | S    | 115     | 73  | s     |
| 20      | 14  | [DEVICE CONTROL 4]     | 52      | 34  | 4       | 84      | 54  | T    | 116     | 74  | t     |
| 21      | 15  | [NEGATIVE ACKNOWLEDGE] | 53      | 35  | 5       | 85      | 55  | U    | 117     | 75  | u     |
| 22      | 16  | [SYNCHRONOUS IDLE]     | 54      | 36  | 6       | 86      | 56  | V    | 118     | 76  | v     |
| 23      | 17  | [END OF TRAN BLOCK]    | 55      | 37  | 7       | 87      | 57  | W    | 119     | 77  | w     |
| 24      | 18  | [SOFT DLE]             | 56      | 38  | 8       | 88      | 58  | X    | 120     | 78  | x     |
| 25      | 19  | [END OF MEDIUM]        | 57      | 39  | 9       | 89      | 59  | Y    | 121     | 79  | y     |
| 26      | 1A  | [SUBSTITUTE]           | 58      | 3A  | :       | 90      | 5A  | Z    | 122     | 7A  | z     |
| 27      | 1B  | [ESCAPE]               | 59      | 3B  | ;       | 91      | 5B  | {    | 123     | 7B  | {     |
| 28      | 1C  | [FILE SEPARATOR]       | 60      | 3C  | <       | 92      | 5C  | \    | 124     | 7C  | \     |
| 29      | 1D  | [GROUP SEPARATOR]      | 61      | 3D  | =       | 93      | 5D  | ]    | 125     | 7D  | }     |
| 30      | 1E  | [RECORD SEPARATOR]     | 62      | 3E  | >       | 94      | 5E  | ^    | 126     | 7E  | -     |
| 31      | 1F  | [UNIT SEPARATOR]       | 63      | 3F  | ?       | 95      | 5F  | -    | 127     | 7F  | [DEL] |

ASCII: American Standard Code For Information Interchange

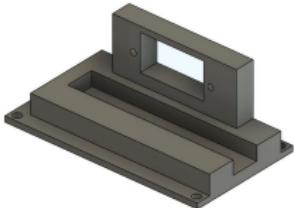


# Keypad.h

```
1 #include <Keypad.h>
2
3 const byte ROWS = 4;
4 const byte COLS = 4;
5 char customKey;
6
7 char hexaKeys[ROWS][COLS] = {
8     {'1', '2', '3', 'A'},
9     {'4', '5', '6', 'B'},
10    {'7', '8', '9', 'C'},
11    {'*', '0', '#', 'D'}
12};
13
14 byte rowPins[ROWS] = {9, 8, 7, 6};      \\keypad leads 8,7,6,5
15 byte colPins[COLS] = {5, 4, 3, 2};      \\keypad leads 4,3,2,1
16
17 Keypad customKeypad = Keypad(makeKeymap(hexaKeys), rowPins, colPins, ROWS, COLS);
18
19 void setup(){
20     Serial.begin(9600);
21 }
22
23 void loop(){
24     customKey = customKeypad.getKey();
25
26     if (customKey){
27         Serial.printf("Key Pressed: %c\n",customKey);
28         Serial.printf("Key Pressed (Hex Code) 0x%02X\n",customKey);
29     }
30 }
```



# Assignment: L06\_02\_Lock



- Notebook:  
schematic
- Fritzing diagram
- Wire your circuit
- Write the code

- ➊ Design and print a lockholder based on the class example.
  - Optional: design and print your own gear and lock slider
- ➋ Using the keypad, create a digital lock
  - Implement 4-digit digital "key" in an array.
  - Use the keypad to enter a code and store the entered code in an array
  - Create a bool function<sup>a</sup> that compares entered code array to the key array
  - Use the servo to lock and unlock based on a correctly entered code.
  - Light green LED and disengage lock when unlocked.
  - Light red LED and engage lock when locked.

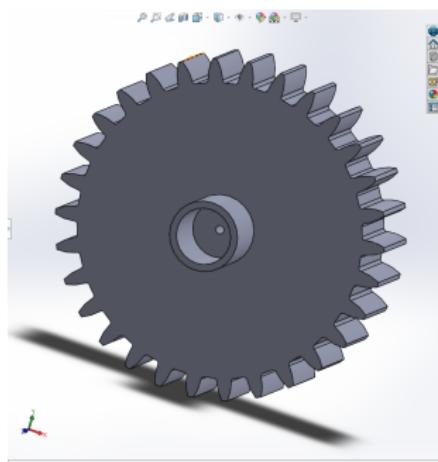
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<sup>a</sup>Remember to use local variables in the function

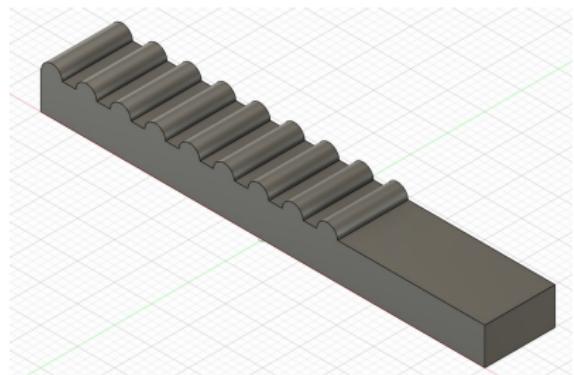


# Optional Designs

GEAR



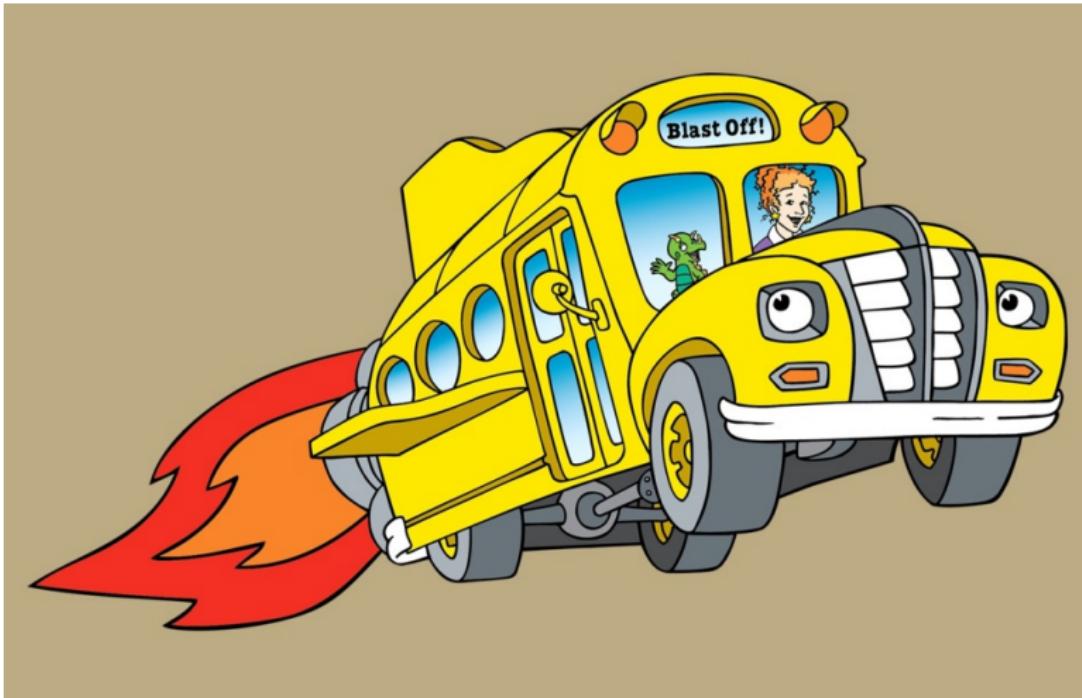
LOCK SLIDER



# Module 7 - $I^2C$

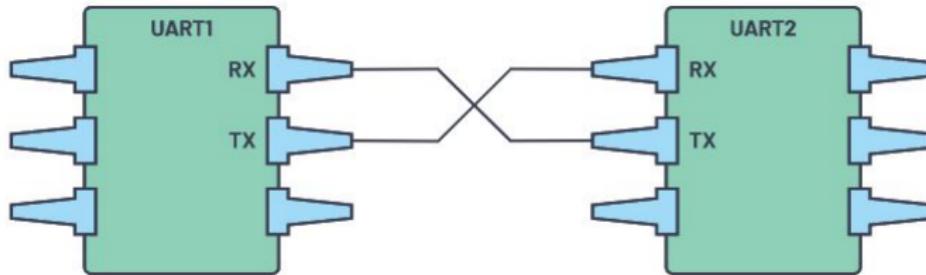


# Buses and Interfaces





# UART

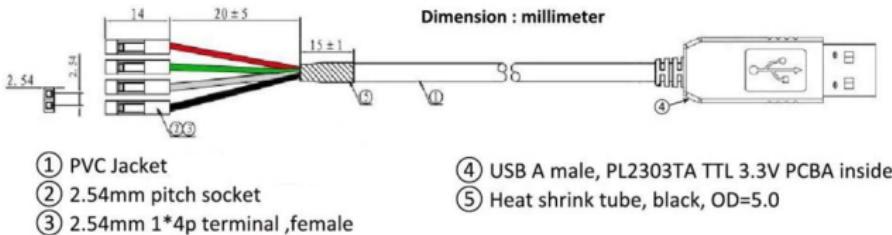


Universal Asynchronous Receiver/Transmitter

- Each device have a transmit (Tx) and receive (Rx) pin.
- UART1 Tx is connected to UART2 Rx (and visa versa)



# The USB Cable is a UART connection

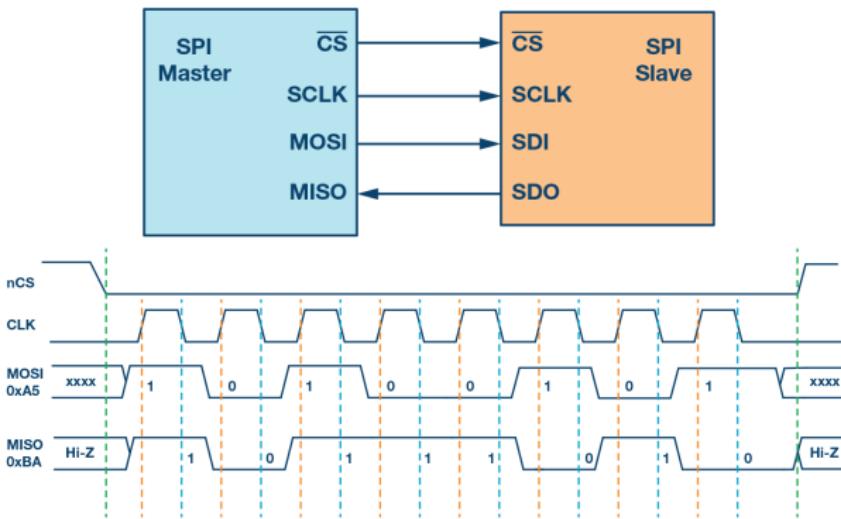


| 1*4P Female Socket | Name | Colour | Description                |
|--------------------|------|--------|----------------------------|
| Pin 1              | TXD  | White  | Transmit Asynchronous Data |
| Pin 2              | RXD  | Green  | Receive Asynchronous Data  |
| Pin 3              | GND  | Black  | Device ground supply       |
| Pin 4              | VCC  | Red    | +5V                        |





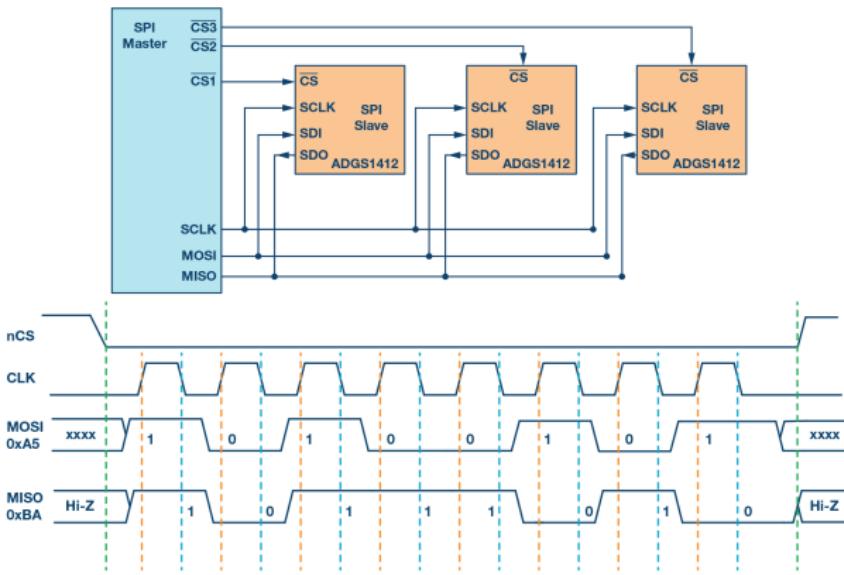
# Serial Peripheral Interface



- Master Out, Slave In (MOSI) connects to Data In
- Master In, Slave Out (MISO) connects to Data Out



# SPI - Chip Select

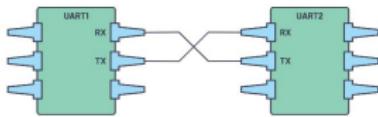


- SPI uses the  $\overline{CS}$  lines to select which peripheral is active.
- Having two SPI devices selected at the same time causes interference.
- In void setup(), always initialize all SPI devices as "off"
  - Note:  $\overline{CS}$  is active LOW ("off" is HIGH)

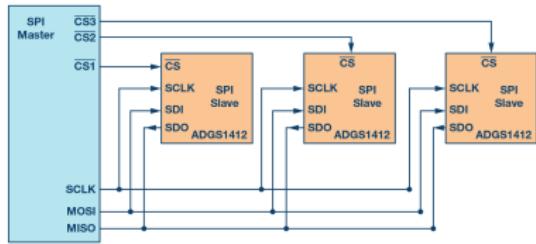


# Serial UART vs SPI

UART

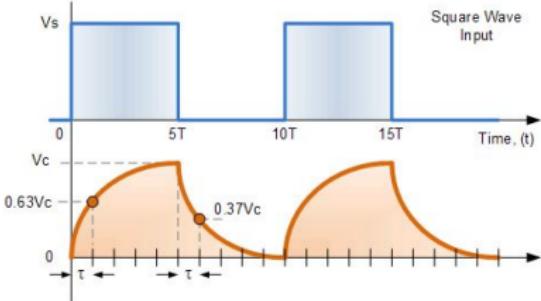
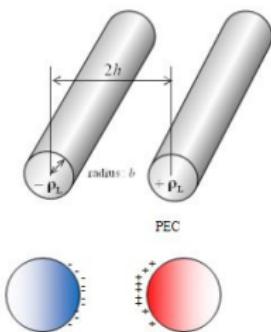


SPI





# RC Time Constant



- Up until now, we have considered wires as ideal conductors; however:
  - Wires have non-zero resistance, longer and thinner wires have more resistance.
  - When two wires are close to each other, there is a parasitic capacitance between them.
- The time constant ( $\tau = \frac{1}{RC}$ ) of an RC circuit determines the amount of time it takes a square wave input to reach 63% of its final value.
- Some communication protocols expect sharp transitions between 0 and 3.3V for clock and data signals.



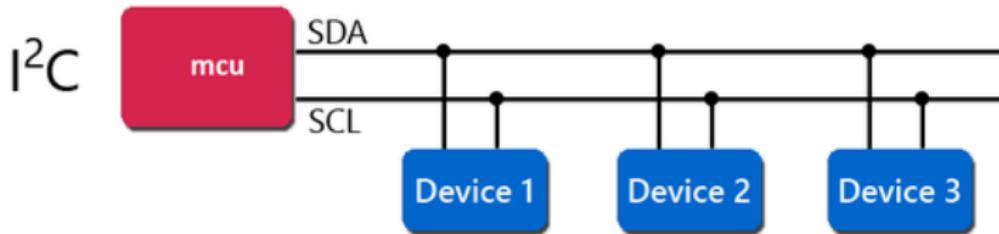
# IoT Humor



Backing Up the Internet of Things



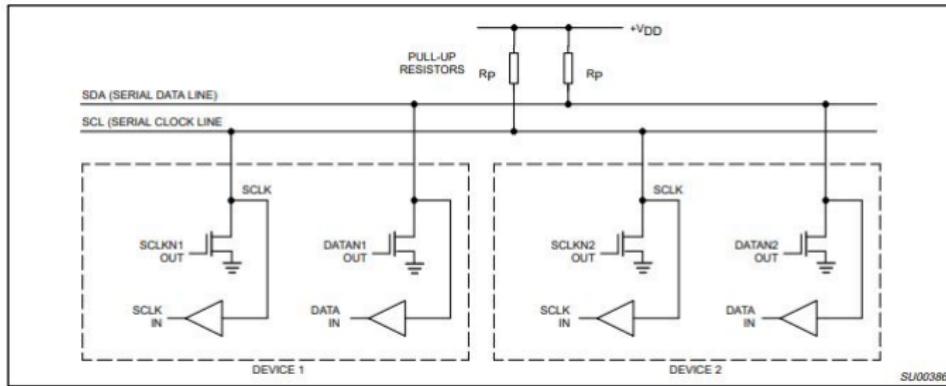
# Inter-integrated Circuit ( $I^2C$ )





# $I^2C$ Pullup Resistors

The  $I^2C$  drivers are "open drain". They can pull the corresponding signal line low, but cannot drive it high. This is done to prevent a short when one device is driving the bus low, while another is driving it high.



Each  $I^2C$  line needs a pull-up resistor on it to restore the signal to high when no device is asserting it low. The Teensy (and Argon) have internal pull-up resistors that are usually sufficient to restore the high signal. For  $I^2C$  greater than 1m, an external 4.7Ω should be added to each line.



# I<sup>2</sup>C vs SPI

## I<sup>2</sup>C v/s SPI

| I <sup>2</sup> C   | SPI   |
|--|---|
| Speed limit varies from 100kbps, 400kbps, 1mbps, 3.4mbps depending on i2c version. | More than 1mbps, 10mbps till 100mbps can be achieved.                 |
| Half duplex synchronous protocol   | Full Duplex synchronous protocol                                      |
| Support Multi master configuration   | Multi master configuration is not possible                            |
| Acknowledgement at each transfer   | No Acknowledgement  |
| Require Two Pins only SDA, SCL   | Require separate MISO, MOSI, CLK & CS signal for each slave.          |
| Addition of new device on the bus is easy  | Addition of new device on the bus is not much easy a I <sup>2</sup> C |
| More Overhead (due to acknowledgement, start, stop)                                | Less Overhead   |
| Noise sensitivity is high  | Less noise sensitivity  |



## L07\_00\_I2CScanner

Let's create an I2C scanner

- ① On your large breadboard, add the BME280 and OLED.
- ② Follow along to create the I2C code.
  - Use library wire.h
  - Wire.begin();
  - Wire.beginTransmission(i);
  - Wire.endTransmission();
    - 0: Transmission Successful
    - 1: Data too long to fit in transmit buffer
    - 2: Received NACK (Negative Acknowledgment) on transmit of address
    - 3: Received NACK on transmit of data
    - 4: Other error
- ③ Determine the I2C addresses of each device, document in your lab notebook.



# Char Datatype - Revisited

Reminder - the char data type is a single byte in size and can be used to represent text characters (ASCII).

| ASCII control characters |                                 | ASCII printable characters |       | Extended ASCII characters |   |
|--------------------------|---------------------------------|----------------------------|-------|---------------------------|---|
| 00                       | NULL (Null character)           | 32                         | space | 64                        | Ø |
| 01                       | SOH (Start of Header)           | 33                         | !     | 65                        | A |
| 02                       | STX (Start of Text)             | 34                         | "     | 66                        | B |
| 03                       | ETX (End of Text)               | 35                         | #     | 67                        | C |
| 04                       | EOT (End of Trans.)             | 36                         | \$    | 68                        | D |
| 05                       | ENQ (Enquiry)                   | 37                         | %     | 69                        | E |
| 06                       | ACK (Acknowledgement)           | 38                         | &     | 70                        | F |
| 07                       | BEL (Bell)                      | 39                         | '     | 71                        | G |
| 08                       | BS (Backspace)                  | 40                         | (     | 72                        | H |
| 09                       | HT (Horizontal Tab)             | 41                         | )     | 73                        | I |
| 10                       | LF (Line feed)                  | 42                         | *     | 74                        | J |
| 11                       | VT (Vertical Tab)               | 43                         | +     | 75                        | K |
| 12                       | FF (Form feed)                  | 44                         | -     | 76                        | L |
| 13                       | CR (Carriage return)            | 45                         | .     | 77                        | M |
| 14                       | SO (Shift Out)                  | 46                         | ,     | 78                        | N |
| 15                       | SI (Shift In)                   | 47                         | /     | 79                        | O |
| 16                       | DLE (Data link escape)          | 48                         | 0     | 80                        | P |
| 17                       | DC1 (Device control 1)          | 49                         | 1     | 81                        | Q |
| 18                       | DC2 (Device control 2)          | 50                         | 2     | 82                        | R |
| 19                       | DC3 (Device control 3)          | 51                         | 3     | 83                        | S |
| 20                       | DC4 (Device control 4)          | 52                         | 4     | 84                        | T |
| 21                       | NAK (Negative acknowledgement)  | 53                         | 5     | 85                        | U |
| 22                       | SYN (Synchronous idle)          | 54                         | 6     | 86                        | V |
| 23                       | ETB (End of transmission block) | 55                         | 7     | 87                        | W |
| 24                       | CAN (Cancel)                    | 56                         | 8     | 88                        | X |
| 25                       | EM (End of medium)              | 57                         | 9     | 89                        | Y |
| 26                       | SVD (Start of verbal data)      | 58                         | :     | 90                        | Z |
| 27                       | ESC (Escape)                    | 59                         | :     | 91                        | Ø |
| 28                       | FS (File separator)             | 60                         | <     | 92                        | Ø |
| 29                       | GS (Group separator)            | 61                         | =     | 93                        | Ø |
| 30                       | RS (Record separator)           | 62                         | >     | 94                        | Ø |
| 31                       | US (Unit separator)             | 63                         | ?     | 95                        | - |
| 127                      | DEL (Delete)                    |                            |       |                           |   |

| ASCII 248      |   |
|----------------|---|
| Ø              | alt + 248<br>(Degree symbol)            |
| most consulted |   |
| ø              | é è ñ ñ with tilde<br>(alt + 164)       |
| █              | black square<br>(alt + 254)             |
| ²              | superscript two, square<br>(alt + 255)  |
| °              | degree symbol<br>(alt + 251)            |
| '              | apostrophe, single quote<br>(alt + 39)  |
| µ              | letter Mu, miro, miornos<br>(alt + 232) |
| ©              | copyright symbol<br>(alt + 164)         |
| ®              | registered trademark<br>(alt + 165)     |
| ³              | superscript three, cube<br>(alt + 252)  |
| á              | á with acute accent<br>(alt + 160)      |

```

1 const char degree = 0xF8; // Decimal 248 = 0xF8
2 float temp = 98.6;
3 void setup() {
4   Serial.begin(9600);
5   //NOTE: extended ASCII characters don't always print correctly to Serial Monitor
6   Serial.printf("My temperature is %0.1f %c", temp, degree);
7 }

```



## A word about example code

Example code is sometime misleading as each author has their own style

- ① .print() and .println() vs. .printf()
  - Some arduino-type embedded controllers don't have .printf() available as a command, so .print() and .println() are used instead.
  - Per the IoT Style Guide, we use .printf()
- ② Serial.printf(F("Hello World"))
  - AMR Cortex is segmented into program memory and data memory.
  - The compiler usually stores Strings as constants in data memory.
  - The F() forces the String to be stored in program memory. This is useful when the data memory is "small"
  - The ARM Cortex compilers automatically store Strings in program memory, so F() is redundant and not needed.
- ③ #define pre-compiler directive
  - #define can be used to create a label that represents a value. Before compiling, the anywhere the label exists in the code, it is replaced by the value.
  - Our IoT Style guide is to use "const datatype NAME=value" instead of "#define NAME value"



# Assignment: I<sup>2</sup>C



- Notebook:  
schematic
- Fritzing diagram
- Wire your circuit
- Write the code

## ① L08\_00\_Exmaple

- Install Adafruit\_SSD1306 library
- Copy the SSD\_1306\_128x64\_i2c example code to your .ino file
- Run example changing the I2C address to match your OLED.
- You will likely get an error and have to remove a random function in the example code. Why?
- In your notebook document the commands to create an object, initialize the object, and the various commands to display text.



# Assignment: I<sup>2</sup>C (Continued)



## ① L07\_01\_OLEDWrite

- Notebook:  
schematic
  - Fritzing diagram
  - Wire your circuit
  - Write the code
- Without cut/paste, using your notes and printf() display:
    - Hello World
    - Your Name using spanish honorific (señor, señora, señorita).
    - Your Birthday (e.g., 04/03/1968) using separate variables for month, day, and year.
  - Rotate screen using setRotation(rot) method.
    - rot is an int from 0 to 3
  - OPTIONAL: Make your own bitmap:  
<https://diyusthad.com/image2cpp> and  
<https://www.reduceimages.com>

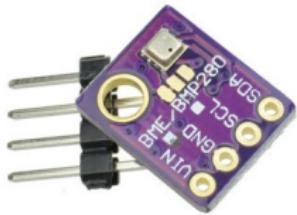


# Using the Adafruit\_BME280 class

```
1 // Define BME280 object
2 Adafruit_BME280 bme; //this is for I2C device
3
4 // Initialize the BME280 in void setup()
5 status = bme.begin(hexAddress);
6 if (status == false) {
7     Serial.printf("BME280 at address 0x%02X failed to
8     start", hexAddress);
9 }
10
11 // Getting data from BME280
12 tempC = bme.readTemperature(); //deg C
13 pressPA = bme.readPressure(); //pascals
14 humidRH = bme.readHumidity(); // %RH
```



# Assignment: $I^2C$



- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

## ① L07\_02\_BME280

- Read BME280 data.
- Convert to tempF and inHg.
- Print to Serial.Monitor and the OLED display.
- Use your NeoPixels to give a visual indication of room conditions.

# Module 8 - Internet



# The Internet





## IP Addresses

- When a device joins the network, it is given an internet address.
    - static or dynamic
  - IPv4 (32-bit) - 4.2 billion
  - IPv6 (128-bit) -  $340 * 10^{27}$  (quadrilliard)
  - In Powershell: ipconfig /all
  - In Terminal (MAC/Linux): ifconfig

## IPv4 address in dotted-decimal notation

172 . 16 . 254 . 1

↓      ↓      ↓      ↓

10101100.00010000.11111110.00000001

8 bits

32 bits (4 bytes)

An IPv6 address (in hexadecimal)

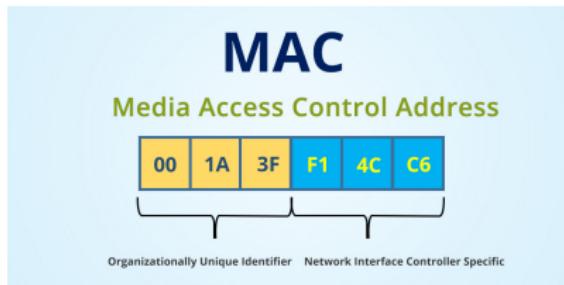
2001:0DB8:AC10:FE01:0000:0000:0000:0000

**2001:0DB8:AC10:FE01::**   Zeroes can be omitted

Y = Y<sub>1</sub> + Y<sub>2</sub> + Y<sub>3</sub> + Y<sub>4</sub> + Y<sub>5</sub>



# MAC Address



A MAC Address is a unique 6-byte (48-bit) address that is usually permanently burned into a network interface card (NIC) and uniquely identifies the device on an Ethernet-based network. The uniqueness of MAC addresses is ensured by IEEE.

If you are creating your own MAC address, the 2's place bit of the first byte, the "locally administered bit" should be set. The 1's place bit, the "globally administered" bit must be off.

Therefore, `xA-xx-xx-xx-xx-xx` is valid, while `x7-xx-xx-xx-xx-xx` is not.



# Finding MAC Address

```
1 SYSTEM_MODE(SEMI_AUTOMATIC)
2 byte mac[6];
3
4 void setup() {
5
6     WiFi.on();
7     WiFi.connect();
8     while(WiFi.connecting()) {
9         Serial.printf(".");
10        delay(250);
11    }
12    Serial.printf("\nWaiting for IP Address\n");
13    delay(1000);
14    Serial.printf("Scan Argon for WiFi Information \n");
15    Serial.printf("ip address: %s \n", WiFi.localIP().toString().c_str());
16    WiFi.macAddress(mac);
17    Serial.printf("mac: %02X:%02X:%02X:%02X:%02X:%02X \n", mac[0], mac[1], mac[2], mac[3], mac
18 [4], mac[5]);
```

Serial monitor opened successfully:  
.....  
Waiting for IP Address  
Scan Argon for WiFi Information  
ip address: 10.0.0.25  
mac: C8:2B:96:B5:30:88



# Forcing Connection to Specific Network

In finding your IP address, you connected to DDCIOT (strongest signal). If there are multiple networks and we want to force connection to a specific network:

```
1 SYSTEM_MODE(MANUAL);
2
3 void setup() {
4     Serial.begin(9600);
5     waitFor(Serial.isConnected, 15000);
6
7     WiFi.on();
8     WiFi.setCredentials("IoTNetwork");
9     // If network requires a password
10    // setCredentials(const ""NetworkName", "Password");
11
12    WiFi.connect();
13    while(WiFi.connecting()) {
14        Serial.printf(".");
15    }
16    Serial.printf("\n\n");
17 }
```



# Assignment: Wemo



- Schematic
- Fritzing diagram
- Wire your circuit
- Write the code

## ① L08\_01\_Wemo

- Using wemo.h, use the button to toggle Wemo on/off (one toggle per press)
- Implement a method to select different Wemo (encoder, second button, etc.)

## ② L08\_02\_Wemo\_Timer

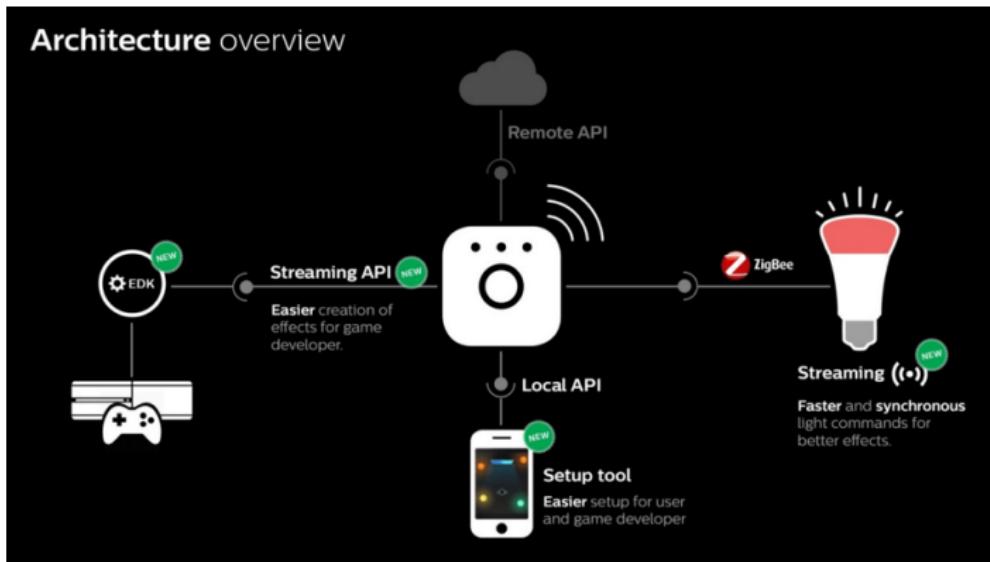
- Create timer that turns off a Wemo 10 secs after you push "off" button without using delay().

## ③ L08\_03\_Wemo\_Object

- Copy wemo.h to wemoObj.h
- Modify it to be use Class and Methods.
- Modify your code to use a wemoObj object.



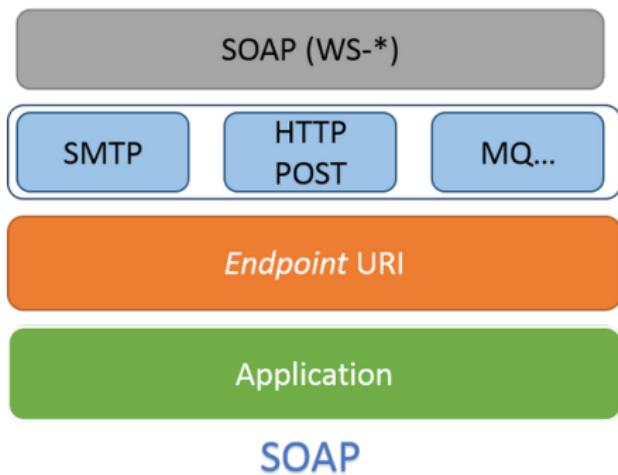
# Phillips Hue API



Application Programming Interface: a set of functions and procedures allowing the creation of applications that access the features or data of an operating system, application, or other service.

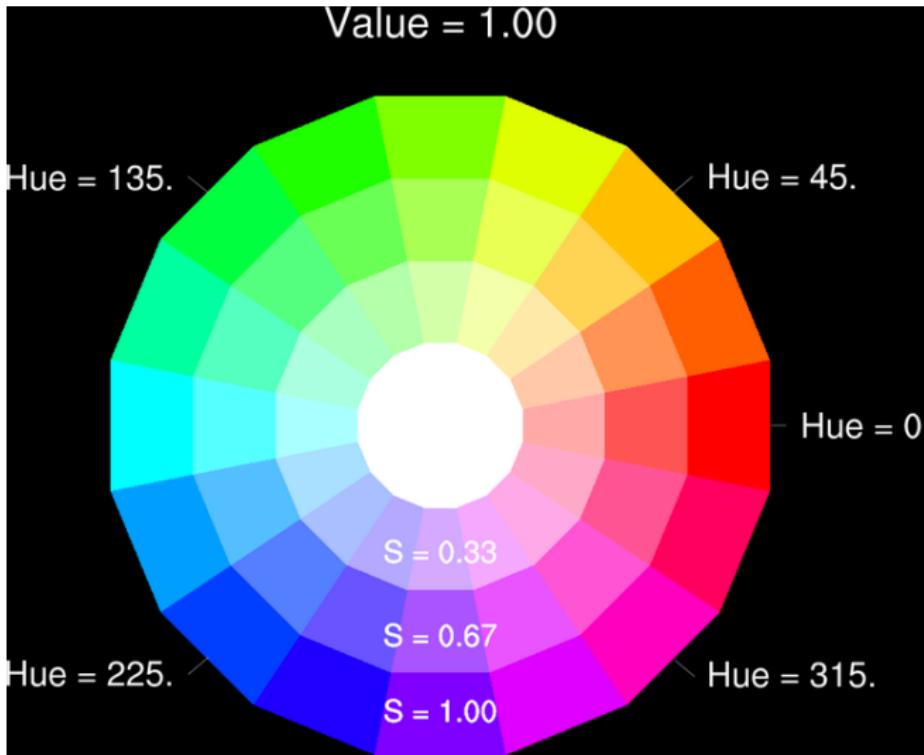


# SOAP vs REST





# HSV Colors





# Assignment: L08\_04\_Hue



- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

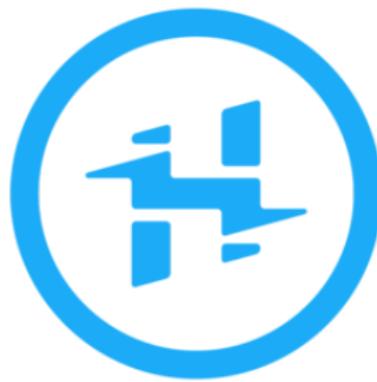
1 Using the hue.h library and L08\_00\_HueHeader as a template, create code that:

- has a button that turns on and off the Hue light at your pod,
- uses the encoder to change the brightness of the Hue bulb,
- has a method of cycling the Hue light through the colors of the rainbow.

# Midterm 1 - Smart Room Controller



# IoT Portfolio

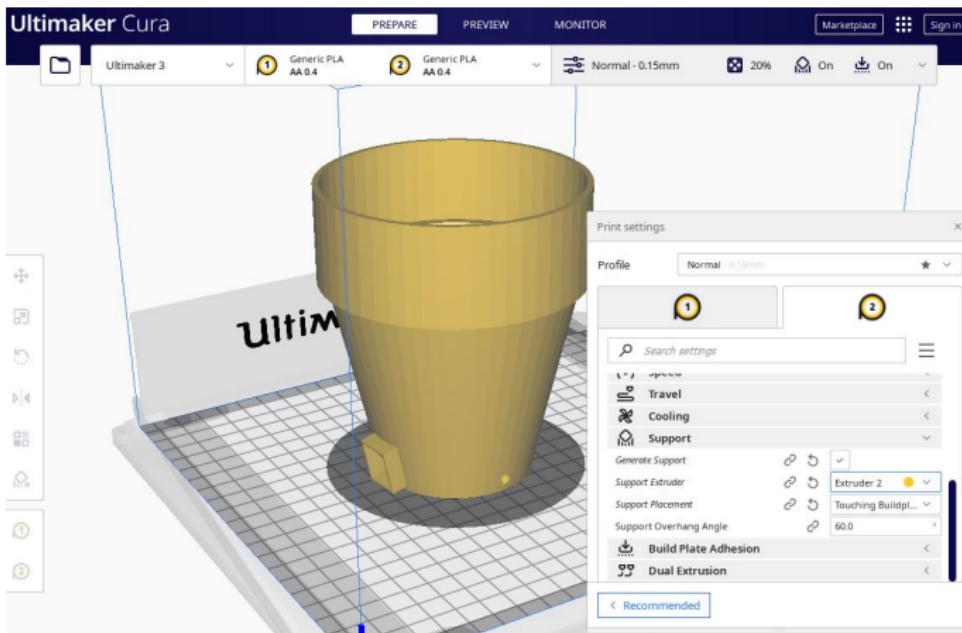


**hackster.io**

Create a [hackster.io](#) account.



# Printing IoT Flowerpot



It is important to change Support Placement to Touching Buildplate.



# Midterm Project - Smart Room Controller

- ① Determine functionality of your Smart Room Controller.
  - Use the components that we have learned over the last 3 weeks.
  - Get minimum requirements from the Instructor.
  - Sketch out the basic layout of your room controller in your lab notebook.
  - Draw flowcharts of the main functions you plan to implement.
  - Get feedback from at least 3 peers on your planned functionality.
- ② Layout your circuitry in Fritzing along with a legible schematic.
- ③ Wire up your circuitry as if you're going to demo your controller for a perspective customer.
- ④ Code, debug, test.
- ⑤ Documentation and Demonstration:
  - Ensure all files are uploaded to GitHub with an appropriate README.md.
  - Upload your project to hackster.io.
  - Prepare a presentation/demonstration for the class on your controller.
  - Participate in class demonstrations (Friday morning - Week 4).



# Smart Room Controller - Minimum Requirements

You are developing a Smart Room Controller prototype that you are going to pitch to a perspective investor.

- ① Control all the Hue lights in the classroom
- ② Control at least two Wemo outlets in the classroom
- ③ Display dynamic messages on the OLED display
- ④ Use at least three additional components (LEDs, buttons, NeoPixels, Encoders, BME280, Servo motor, etc.)
- ⑤ Device has at least two modes
  - Manual - user controls lights and outlets
  - Automatic - external source triggers response of lights and/or outlet(s)
- ⑥ 3D design and print at least one part (button cover, knob, logo, etc.)
- ⑦ A component made at FUSE - laser, wood, metal (case, stand, etc.)
- ⑧ Extra Credit: use a component that we haven't learned in class
- ⑨ Extra Extra Credit: create a custom bitmap for your display